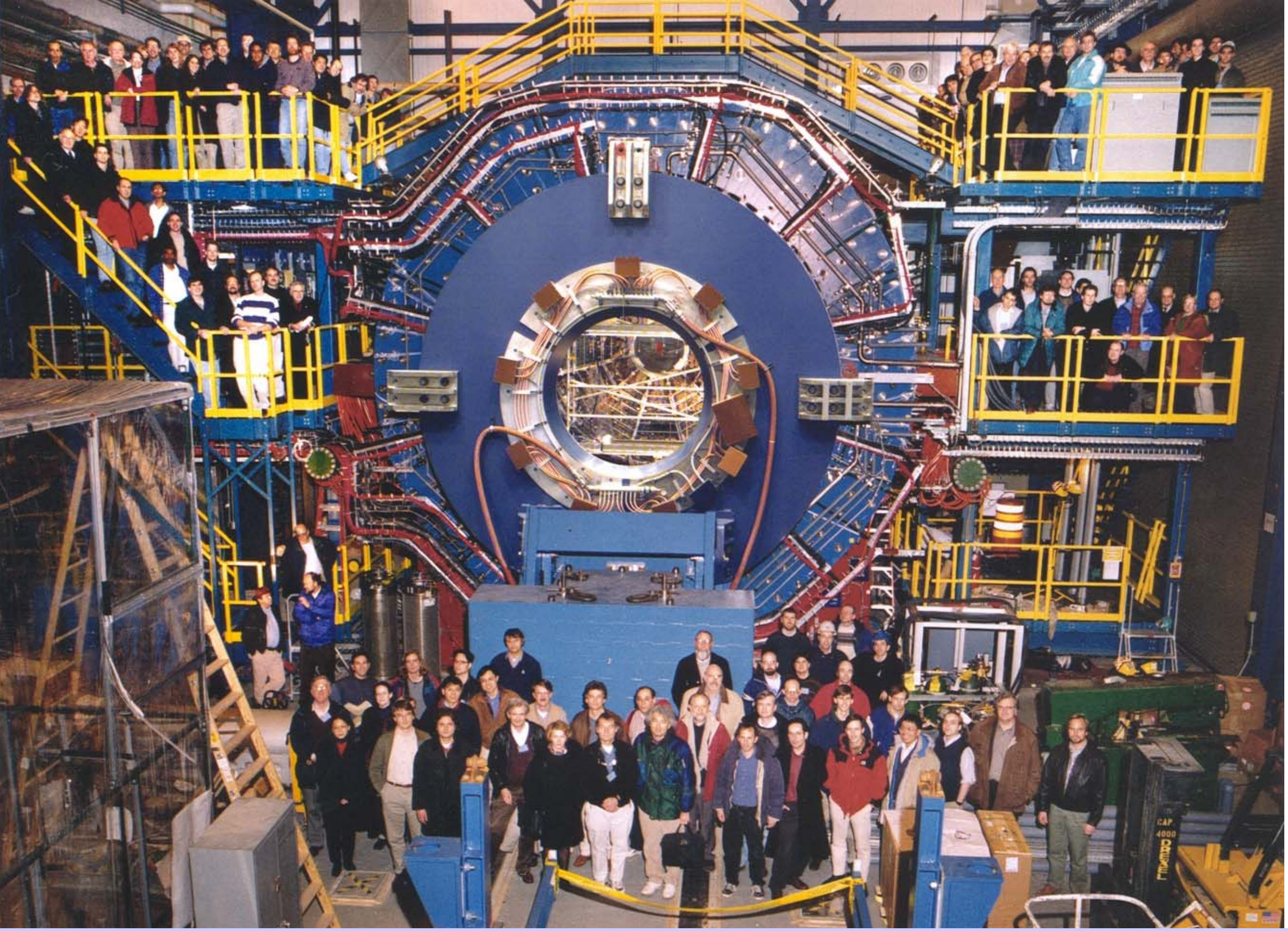
STAR Spin Program

OUTLINE

- Goals and priorities
- Accomplishments
- Status
- Plans, Prospects and Issues

L.C. Bland, for the STAR Collaboration
Brookhaven National Laboratory
RHIC Program Review, 30 June 2004



The STAR Collaboration

~ 400 collaborators
34 institutions
8 countries

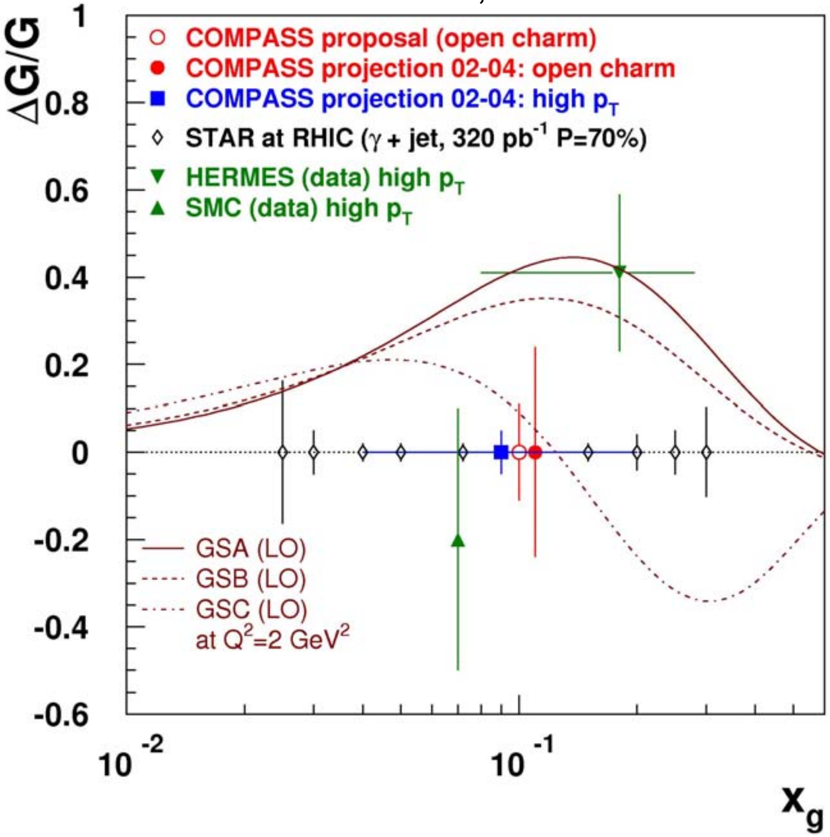
Strong new STAR spin interest from:
CalTech, LBNL, MIT, Valparaiso U., Zagreb

Brazil: Sao Paolo
England: Birmingham
Germany: Frankfurt, MPI - Munich
China: IHEP - Beijing, IPP - Wuhan
France: IReS - Strasbourg, SUBATECH-Nantes
Poland: Warsaw University of Technology
Russia: MEPHI - Moscow, JINR - Dubna, IHEP - Protvino

U.S.: Argonne, Berkeley, Brookhaven National Laboratories
UC Berkeley, UC Davis, UCLA, Creighton, Carnegie-Mellon, Indiana, Kent State, MSU, CCNY, Ohio State, Penn State, Purdue, Rice, Texas, Texas A&M, Washington, Wayne, Yale Univ.

Goals and Priorities

From F.-H. Heinsius, DIS2004



GS A,B,C are models of gluon polarization consistent with polarized deep inelastic scattering data.

T. Gehrmann and W.J. Stirling, Phys. Rev. D**53** (1996) 6100.

- Determine gluon contribution to the proton's spin…

$$\tfrac{1}{2} = \langle S_q \rangle + \langle S_G \rangle + \langle L_q \rangle + \langle L_G \rangle \Big|_{Q^2}$$

$$\langle S_q \rangle \approx 0.1, \text{ from polarized DIS}$$

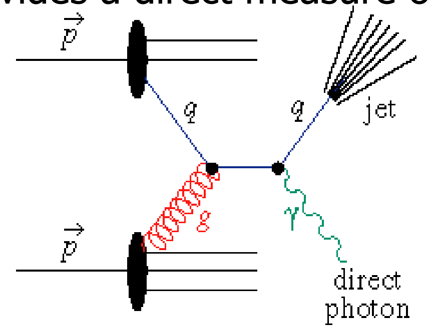
$$\langle S_G \rangle = \int_0^1 \Delta G(x, Q^2)\, dx$$

- Determine flavor separation of quark polarization

- Establish transverse spin structure of the nucleon

Gluon Contribution to the proton's spin

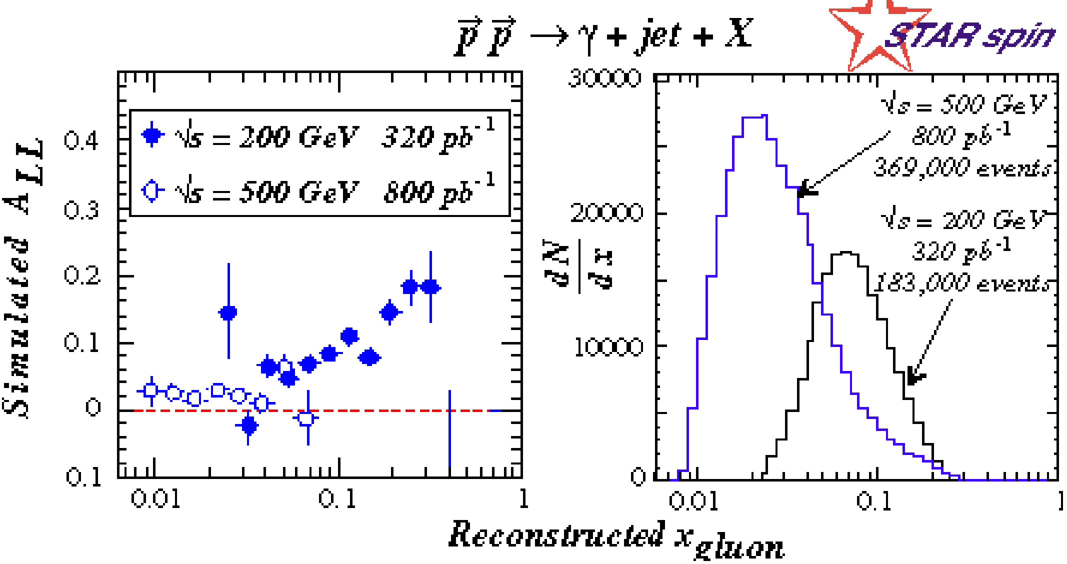
qg Compton scattering with polarized protons provides a direct measure of gluon polarization.



Quark-Gluon Compton scattering

$\vec{p} + \vec{p} \to \gamma\,(+\,jet) + X$

Coincident detection of γ and away-side jet ⇒ event determination of initial-state partonic kinematics.



Measure spin-correlation parameter (A_{LL}) with longitudinally polarized protons

$$P_{b1} P_{b2} A_{LL} = \frac{N_{++} - R N_{+-}}{N_{++} + R N_{+-}}$$

$P_{b1(2)}$ — *beam pol'n (~70%)*

$N_{++(+-)}$ — *equal (opposite) helicity yield*

R — *relative luminosity*

Interpret measured asymmetry within leading-order pQCD

$$A_{LL} = \overbrace{P_{part.\,1} P_{part.\,2}}^{\text{parton pol'ns.}} \hat{a}_{LL} = \underbrace{\overbrace{\frac{\Delta f_1}{f_1} \frac{\Delta f_2}{f_2}}^{\text{pol struct fncs.}}}_{\text{unpol struct fncs.}} \hat{a}_{LL}(\hat{s}, \hat{t}, \hat{u}) \xrightarrow[\text{QCD Compton}]{} \boxed{\frac{\Delta G(x_g)}{G(x_g)}} A_1^p(x_q)\, \hat{a}_{LL}$$

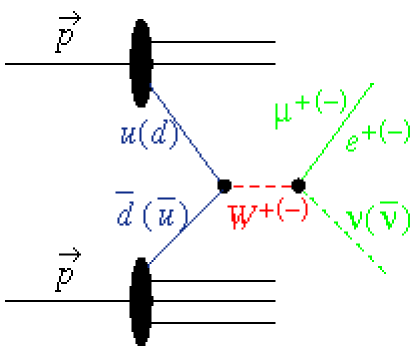
pQCD result for specific process

gluon polarization

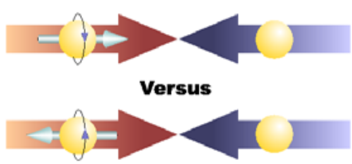
Measured in polarized deep-inelastic scattering

Quark Polarizations Accessed from W± Production

- W± production in pp collisions forms the best means to probe the flavor structure of QCD sea
- Parity violating single-spin asymmetries at RHIC provide access to the quark flavor structure of the proton spin:



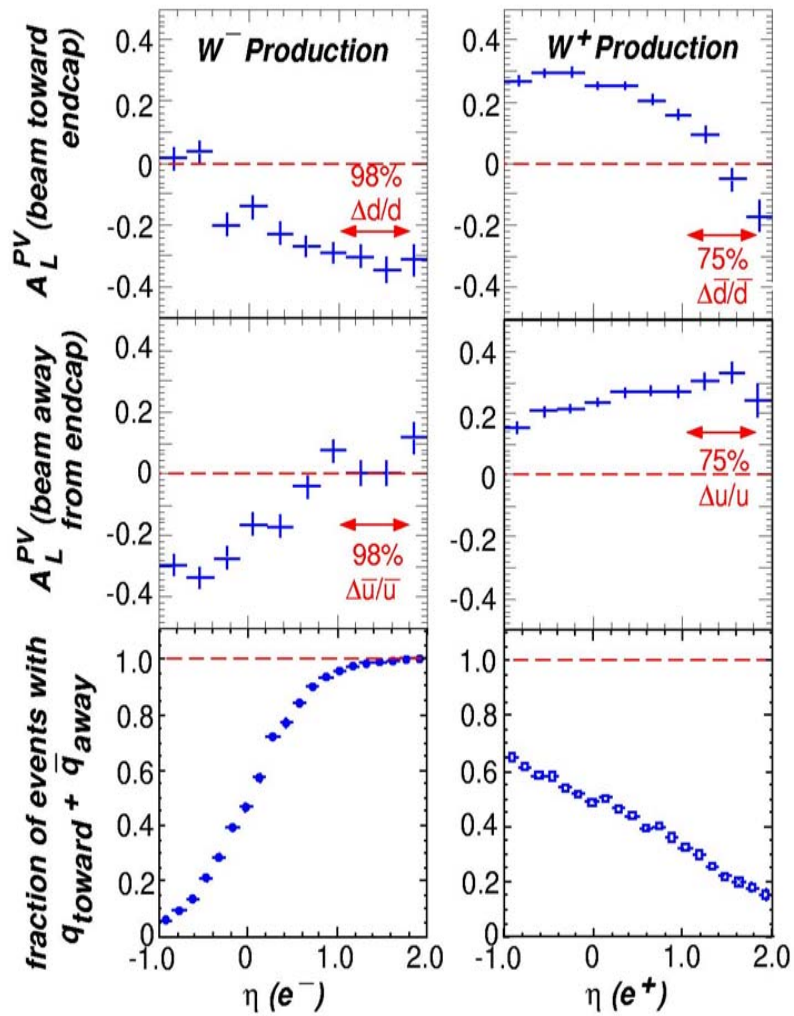
$$\Delta d + \bar{u} \rightarrow W^-$$
$$\Delta \bar{u} + d \rightarrow W^-$$
$$\Delta \bar{d} + u \rightarrow W^+$$
$$\Delta u + \bar{d} \rightarrow W^+$$



$$A_L = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

- Charge sign discrimination of highly energetic forward electrons/positrons is necessary to gain direct sensitivity to the quark and anti-quark polarizations by flavor:

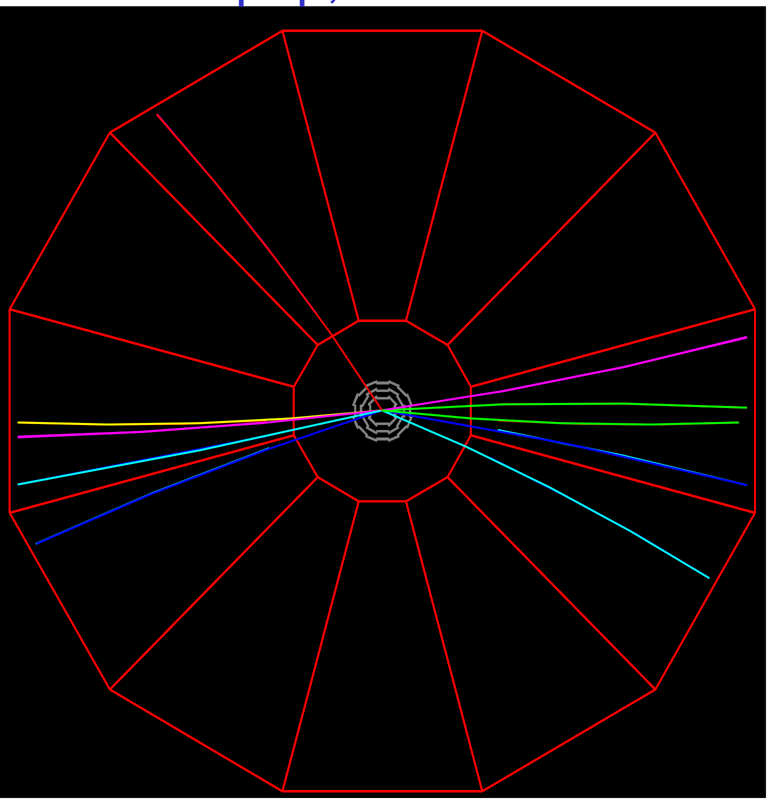
$$\vec{p} + p \rightarrow W^{\pm} + X \rightarrow e^{\pm} + X$$
$$\sqrt{s} = 500\,\mathrm{GeV}, 800\,\mathrm{pb}^{-1}, P_{beam} = 70\%$$



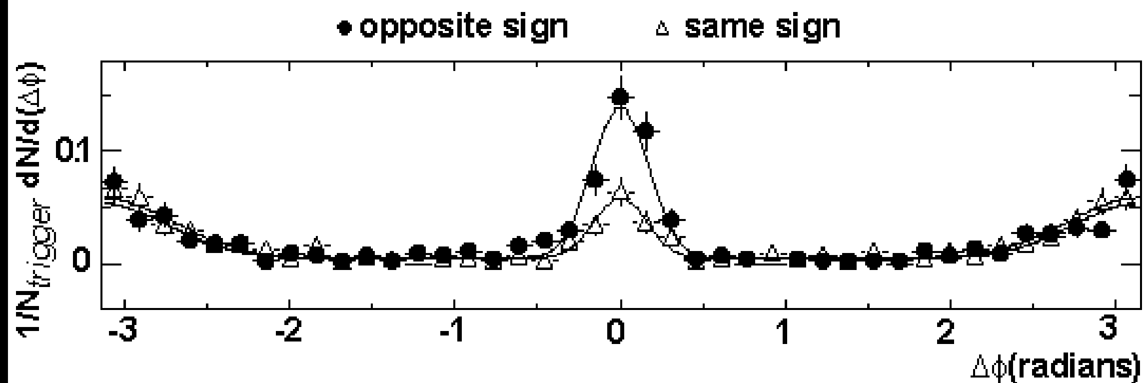
Accomplishments

[redacted]eavy-Ion Physics
[redacted]o spin program)

STAR p+p, √s = 200 GeV



Hadronic high-p_T azimuthal correlations in *pp* collisions



Phys. Rev. Lett. **90** (2003) 082302

Run 2: pp reference data for STAR heavy-ion program

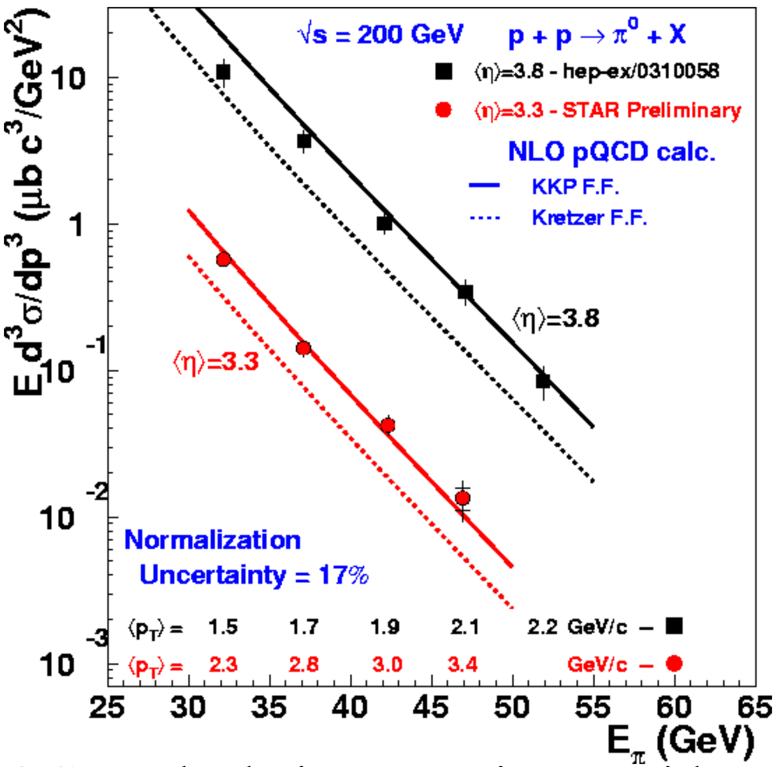
- di-hadrons serve as good di-jet surrogates for heavy-ion collisions.
- clear near-side and away-side di-hadron correlations in *pp* collisions serve as contrast for central AuAu collisions where away-side correlations are strongly suppressed.

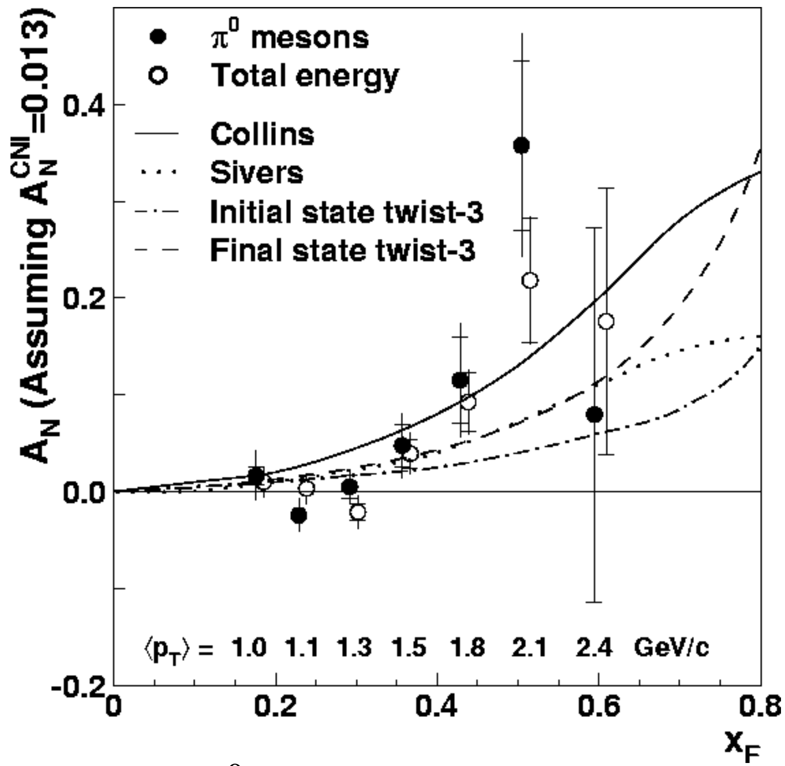
Forward π^0 Production

STAR collaboration, PRL **92**, 171801 (2004)

$$A_N = \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow} = \frac{1}{P_{beam}} \frac{N_\uparrow / L_\uparrow - N_\downarrow / L_\downarrow}{N_\uparrow / L_\uparrow + N_\downarrow / L_\downarrow}$$

- $N_{\uparrow(\downarrow)}$ is spin up (down) π^0 yield
- $L_{\uparrow(\downarrow)}$ is spin up (down) integrated luminosity





- pQCD calculations consistent with measured large-η π^0 cross sections
- Large transverse single-spin effects observed for $\sqrt{s}$ = 200 GeV *pp* collisions

Collins effect ⇒ transversity Sivers effect ⇒ orbital angular momentum

Additional measurements required to disentangle contributions

Beam Beam Counters - Transverse Single Spin Asymmetries

Single spin asymmetries in p+p -> A + X, A- hit(s) from charged particles in the BBC

Left-Right

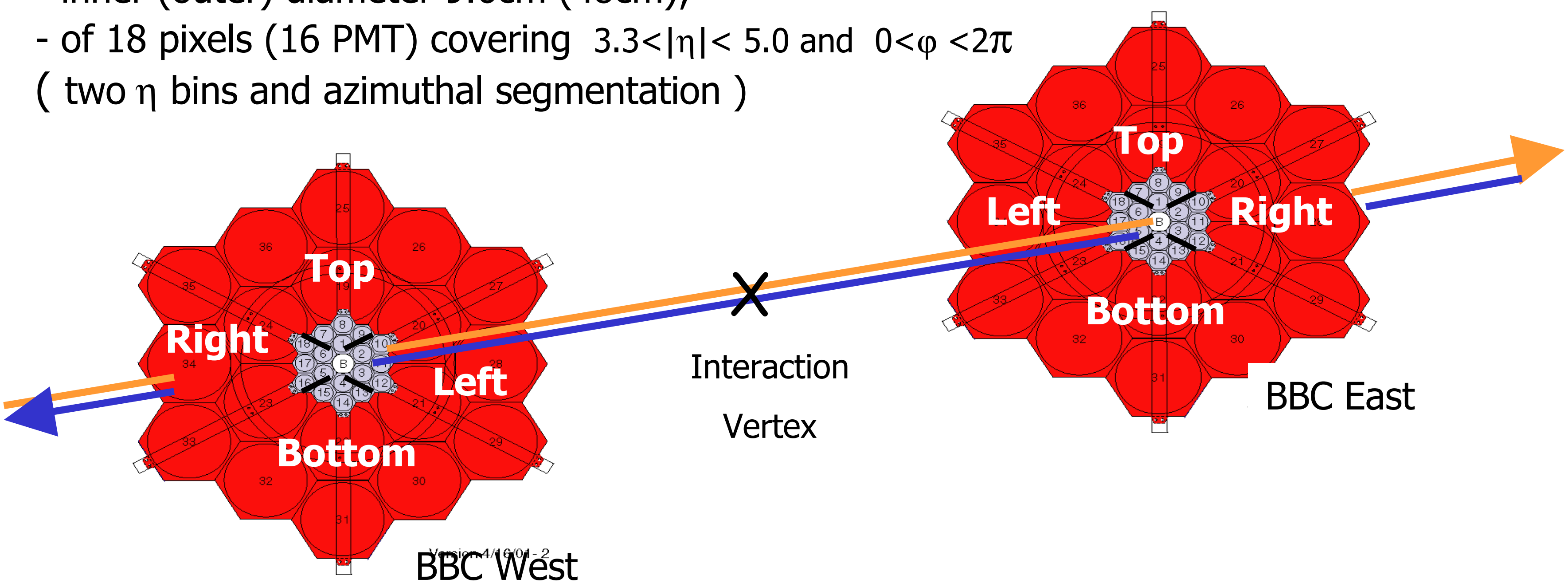
Top-Bottom

$N_{L(R)}$ – number of counts in the BBC East or BBC West (small annuli) counted every bunch crossing by the scaler system

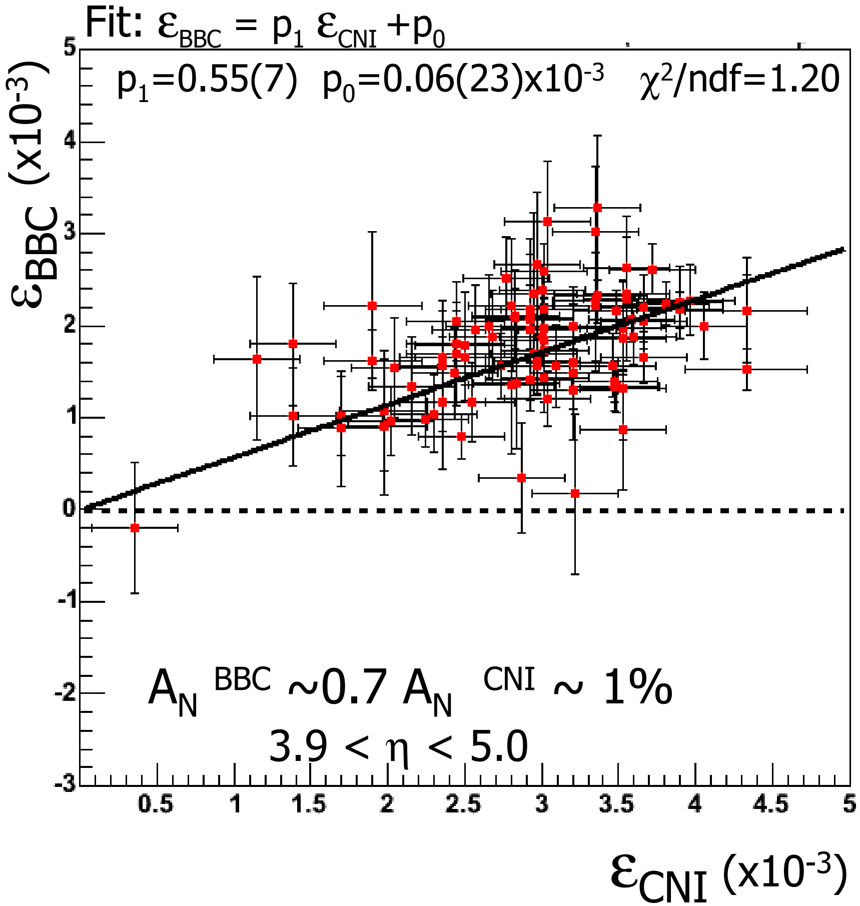
BBC small hexagonal annulus:

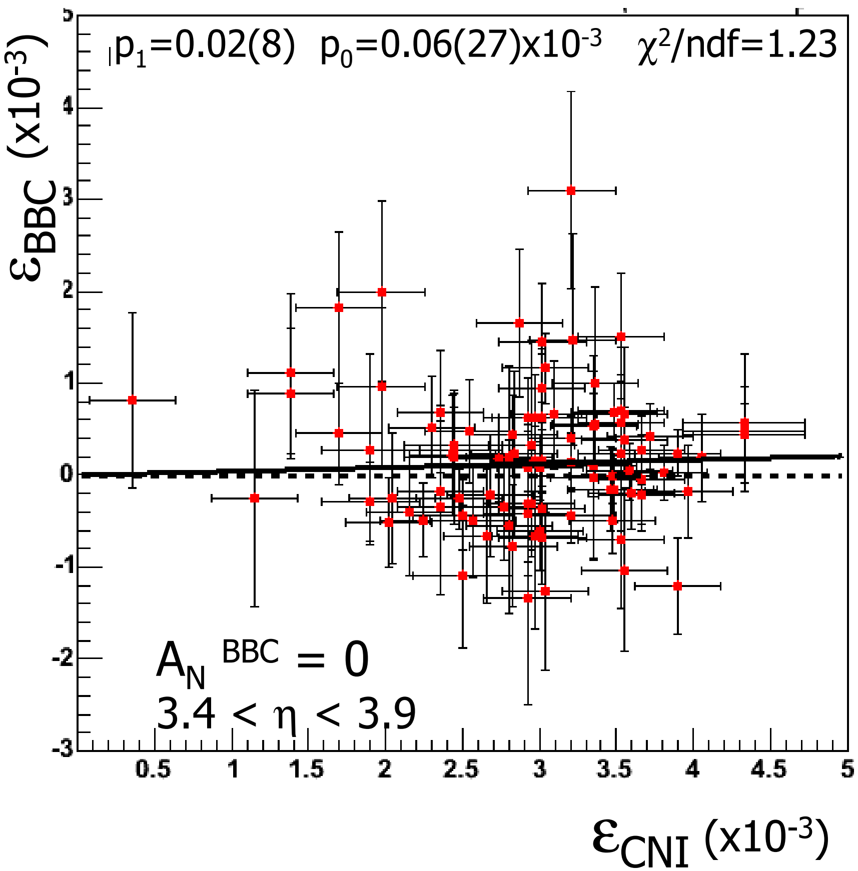
- inner (outer) diameter 9.6cm (48cm);
- of 18 pixels (16 PMT) covering $3.3<|\eta|<5.0$ and $0<\varphi<2\pi$

(two η bins and azimuthal segmentation)



Transverse Single Spin Asymmetries BBC Run-3 (Preliminary) Results

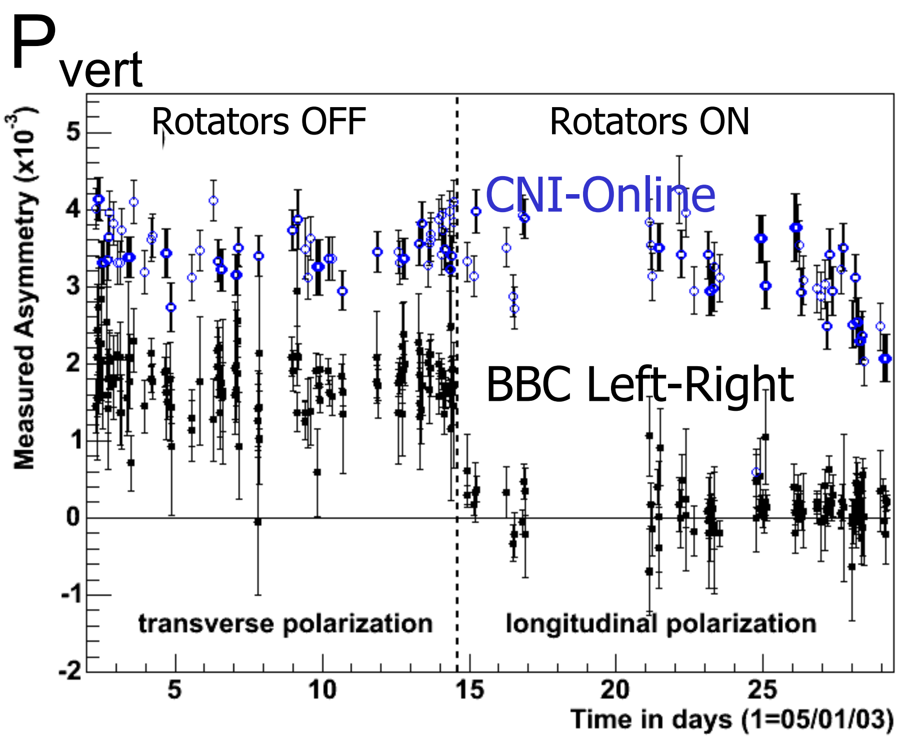


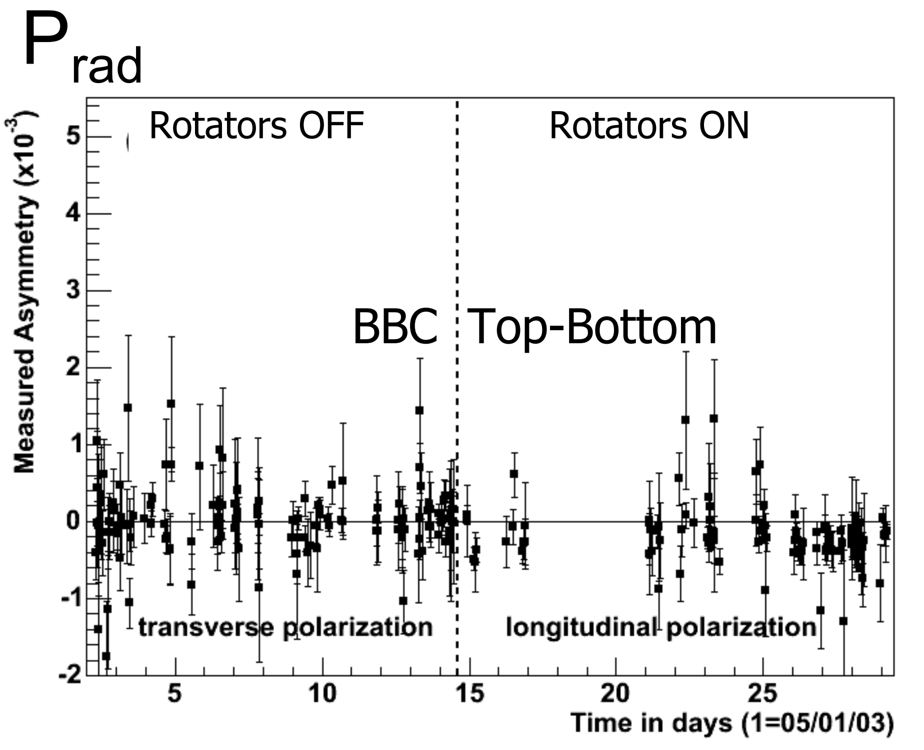


- Strong pseudorapidity dependence of A_N for x_F>0 (A_N = 0 for x_F<0)
- BBC - fast local polarimeter at STAR

Beam Beam Counters

local polarimeter at STAR

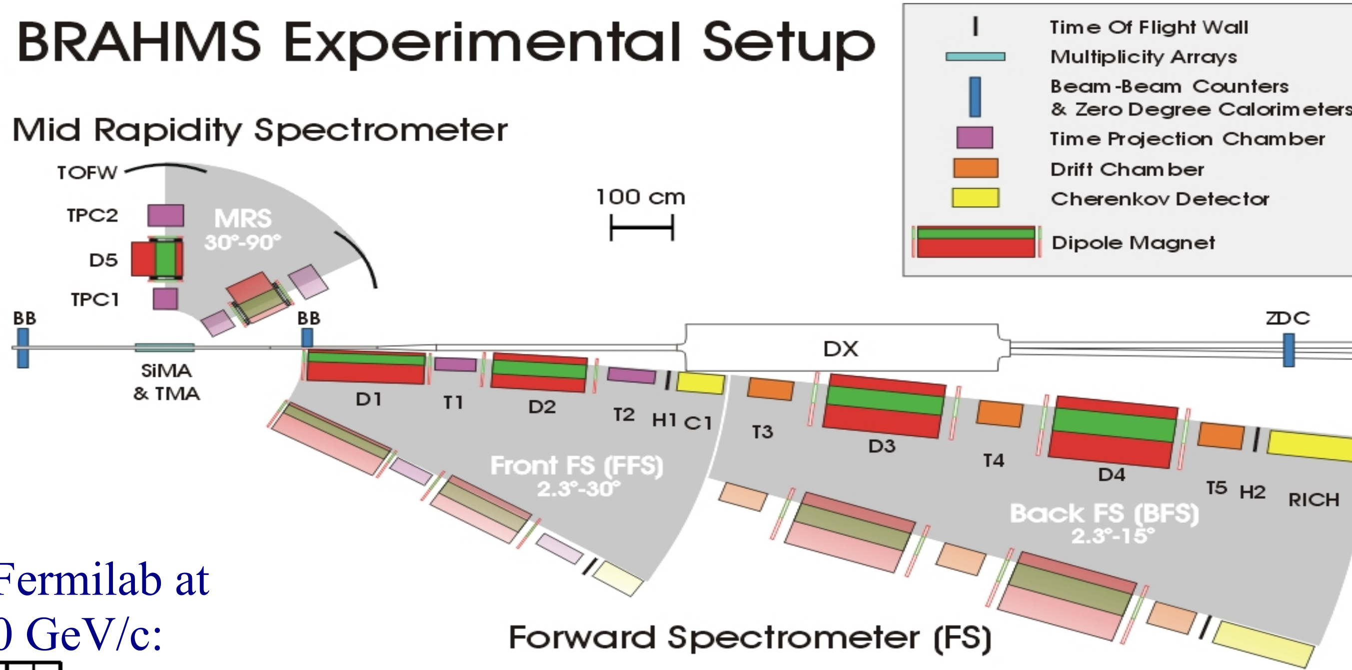




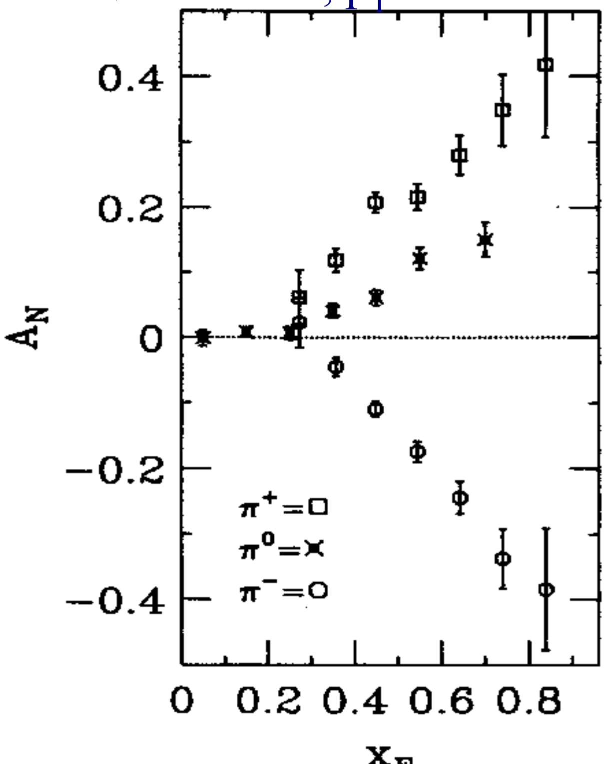
Longitudinal polarization confirmed for the first time at STAR IR in Run-3

BRAHMS Experimental Setup

Future measurements of transverse spin effects also possible at BRAHMS. Measure x_F dependence of charged pion ($\pi^{\pm}$) analyzing power.



A_N measured in E704 at Fermilab at $\sqrt{s}$=20 GeV, p_T=0.5-2.0 GeV/c:



BRAHMS proposal:

measure A_N for $p_{\uparrow}p \rightarrow \pi^{\pm} + X$ at $\sqrt{s}$=200 GeV, η_{π}~3.9

π^+ measurements			*π^- measurements*		
x_F	p_T(GeV/c)	Cts/hour	x_F	p_T(GeV/c)	Cts/hour
0.21	1.0	6454	0.21	1.0	5296
0.25	1.4	1068	0.25	1.4	807
0.30	1.9	163	0.30	1.9	91
0.35	2.5	24	0.35	2.5	12

Rate estimates
Assume
$\mathcal{L}$ ~ 1.5 $\mu b^{-1}s^{-1}$

Disentangling Contributions to A_N

Proposed STAR measurement for run 5

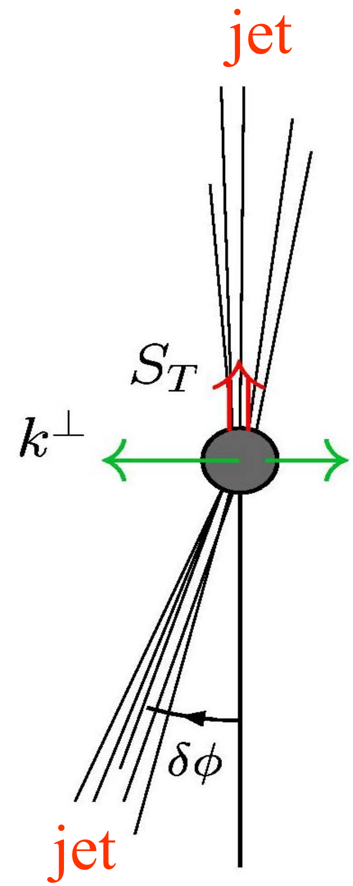
Sivers function:

• requires spin-correlated transverse momentum ($\boldsymbol{k}_\perp$) in distribution function for proton with momentum $\boldsymbol{P}$:

$$\Delta^N f(x,\boldsymbol{k}_\perp,\boldsymbol{S}_\perp)\frac{\boldsymbol{S}_\perp\cdot(\boldsymbol{P}\times\boldsymbol{k}_\perp)}{|\boldsymbol{S}_\perp||\boldsymbol{P}||\boldsymbol{k}_\perp|}$$

• related to parton orbital angular momentum (with possible connection to generalized parton distributions).

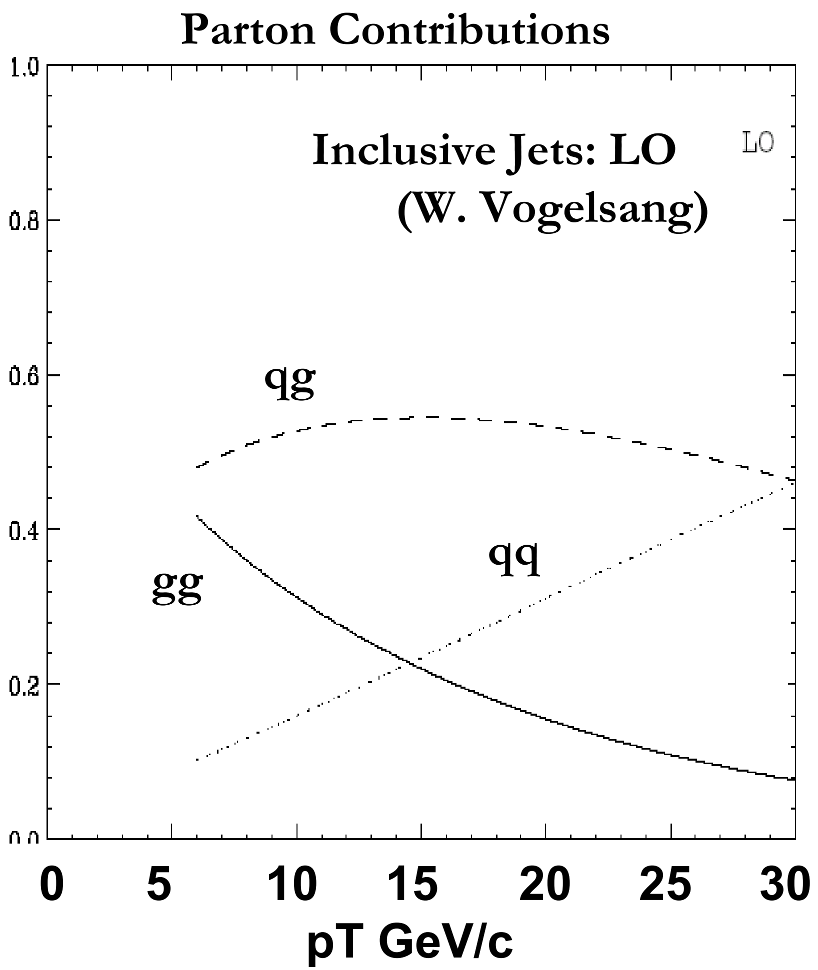
• gluon Sivers function accessible through spin-correlated mid-rapidity dijet azimuthal correlations.

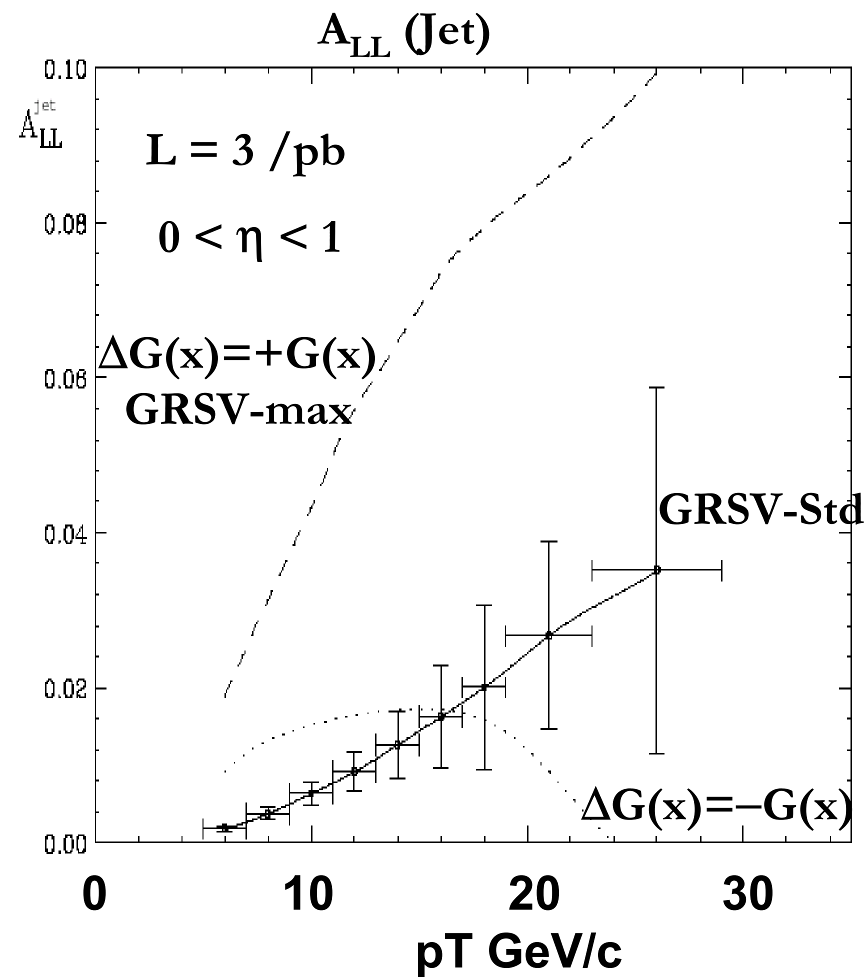


Daniel Boer and Werner Vogelsang, Phys.Rev. D **69** (2004) 094025

Jet Sensitivity to Gluon Polarization

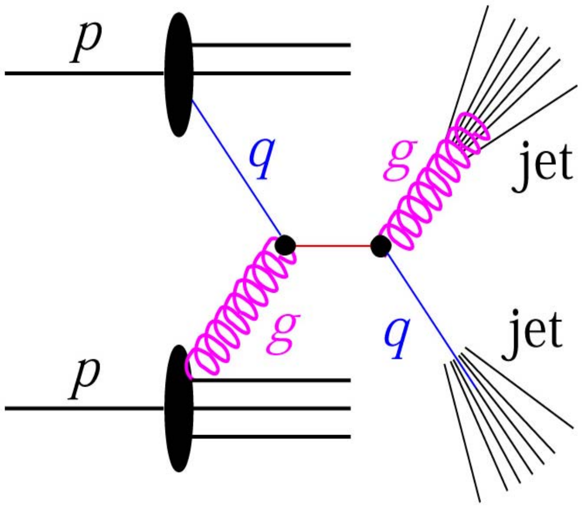
GRSV models of gluon helicity asymmetry distribution, $\Delta G(x)$, from
M. Gluck, E. Reya, M. Stratmann and W. Vogelsang, Phys. Rev. D63 (2001) 094005



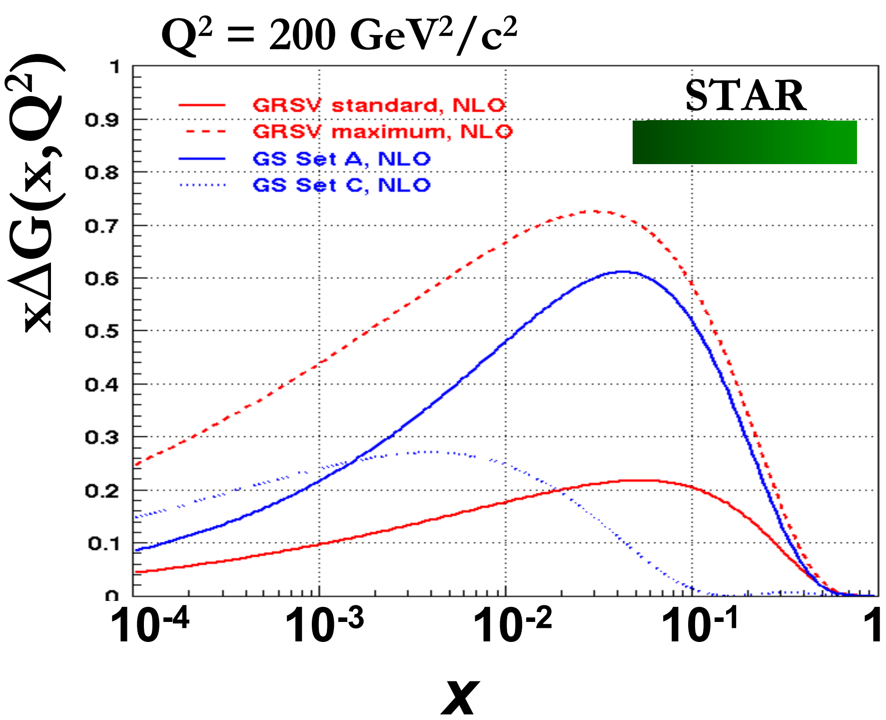


Inclusive jet production provides good sensitivity to $\Delta G(x)$.

Kinematic Range



- Polarized proton collisions
- $\sqrt{s}$ = 200 GeV
- Jet E_T 5-50 GeV
- Pseudorapidity $0 < \eta < 1$

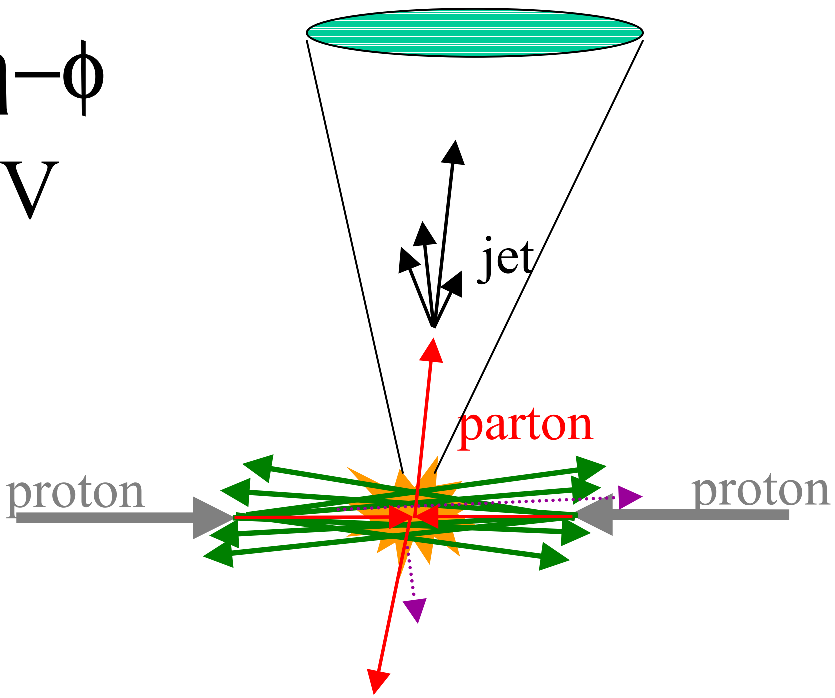


- Large Asymmetry
- Sensitivity to Large ΔG
- Dominant Reaction Mechanism

Jet Finder: Charged Jets

For this analysis, Jets are defined as a grouping of one or more (charged) tracks measured in the TPC and satisfying the following requirements…

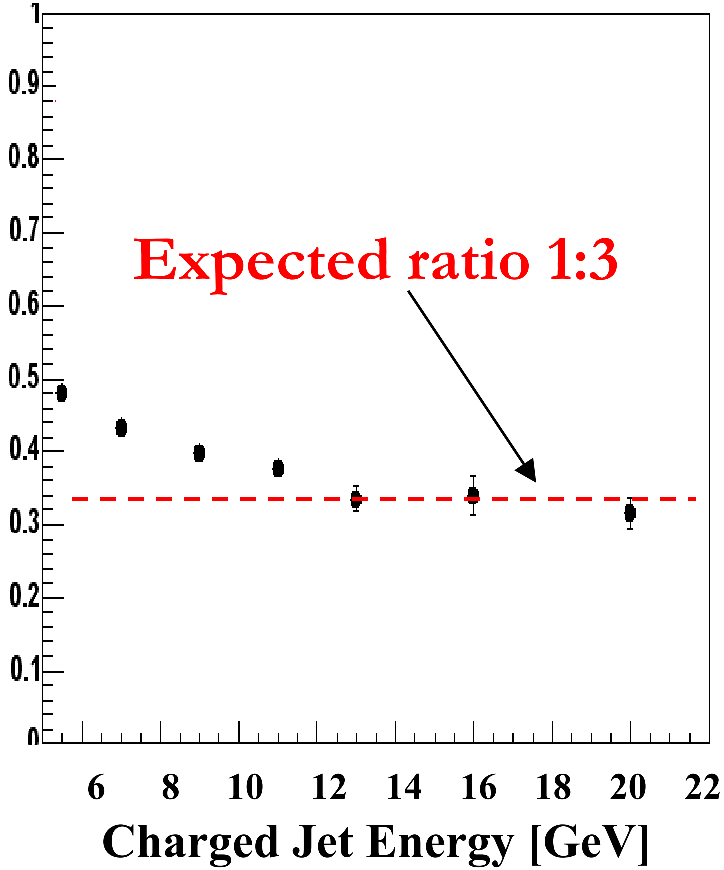
- Using an Iterative, Midpoint, Cone Algorithm*
- Cone Angle = 0.7 in $\eta-\phi$
- Seed Energy = 0.5 GeV
- pT Track > 0.1 GeV/c
- $-1.6 < \eta_{tracks} < +1.6$
- pT Jet > 5 GeV



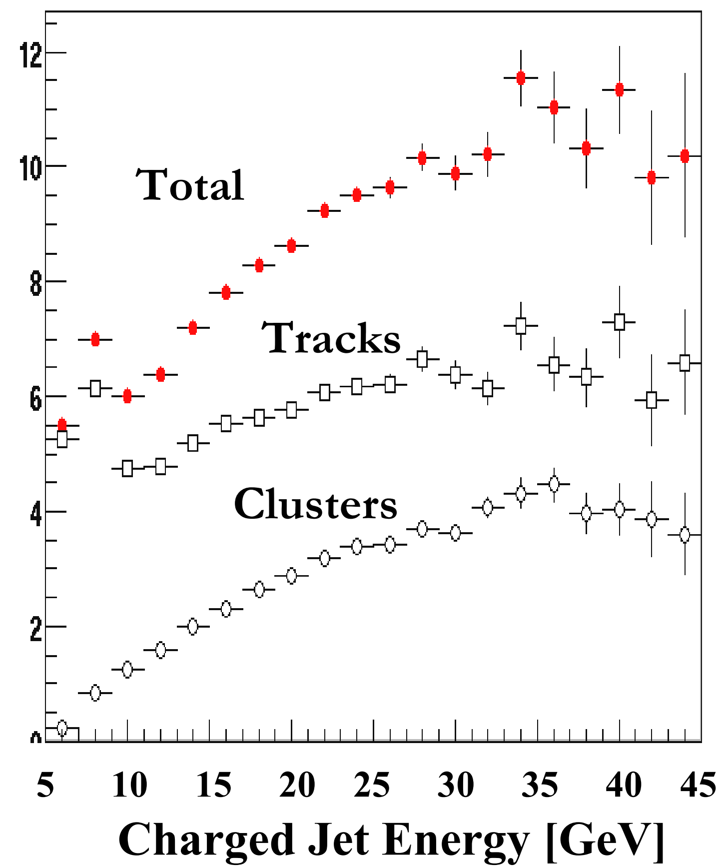
*** Blazey et al hep-ex/0005012 (SNOMASS)**

Trigger Bias: Neutral Energy Fraction

Neutral E_T/Total Jet E_T



Track and Cluster Multiplicities



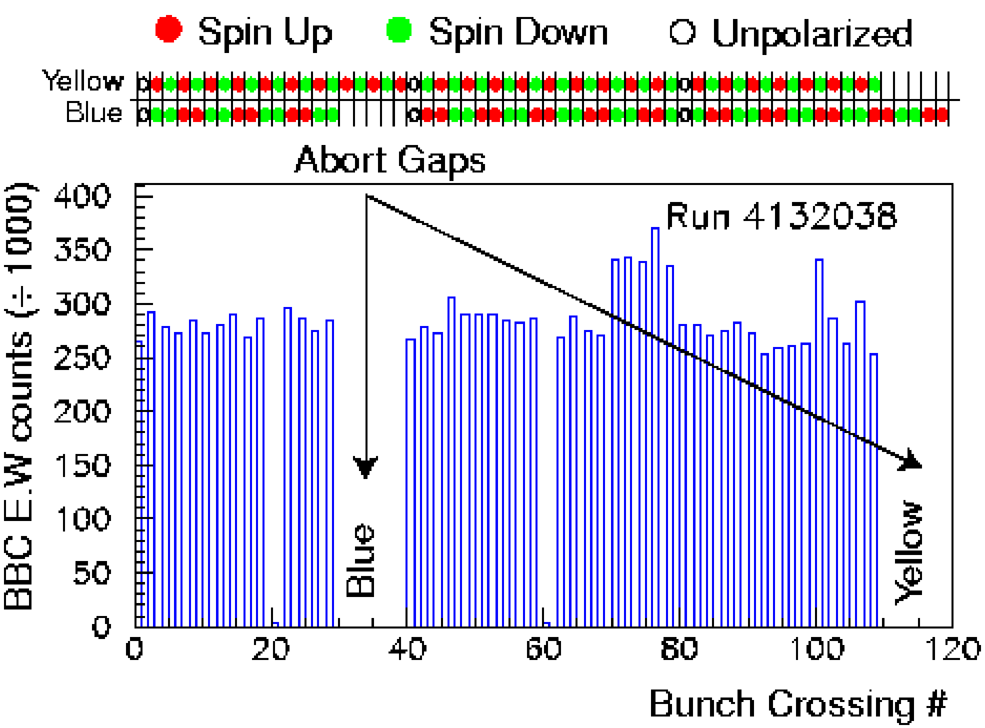
Jets are found in the data

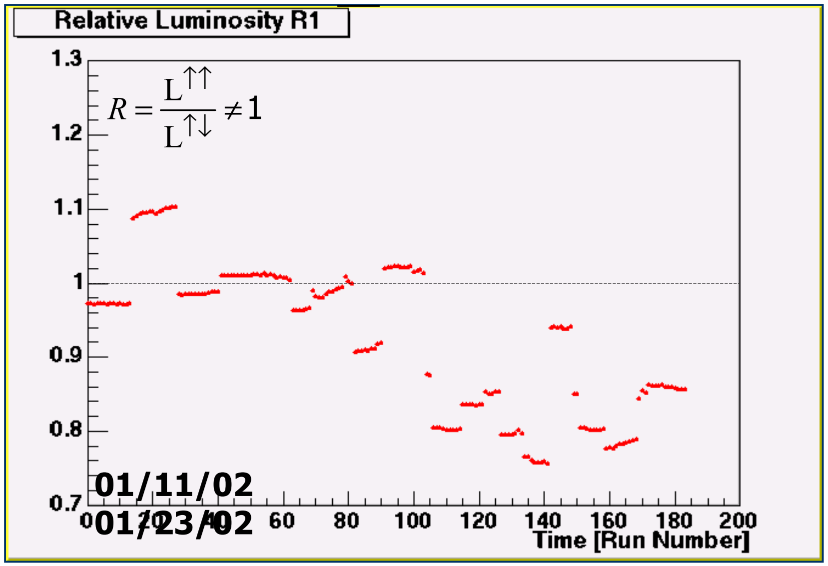
Quantitative understanding of trigger bias (EMC trigger) and jet energy scale is still required.

Relative Luminosity Determination

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{1}{P_1 P_2} \times \frac{N_{++} - R N_{+-}}{N_{++} + R N_{+-}} \qquad R = \frac{L_{++}}{L_{+-}}$$

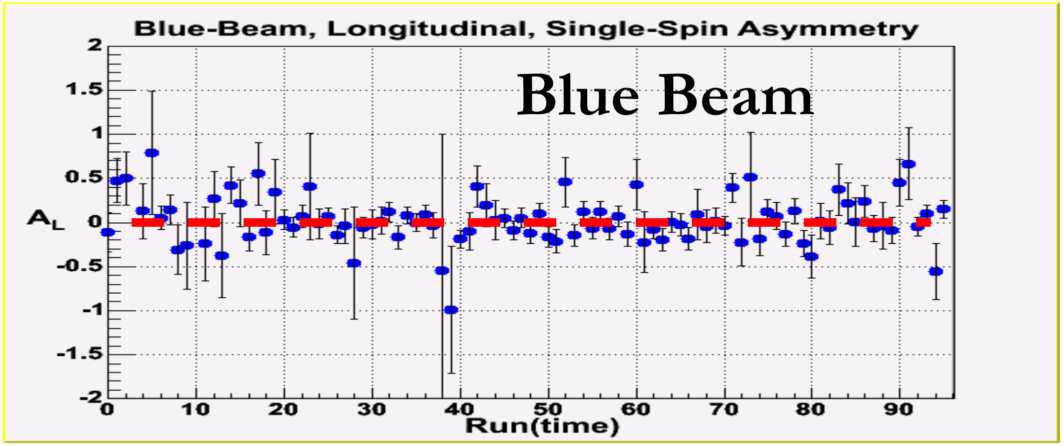
- $N_{++(+-)}$ is equal (opposite) helicity yield
- $L_{++(+-)}$ is integrated luminosity for equal (opposite) helicity collisions



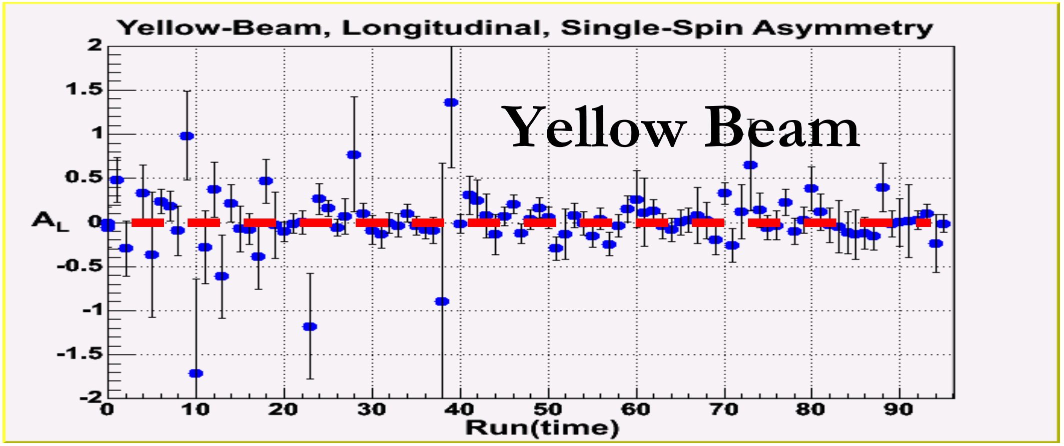


Error on A_{LL} from Relative Luminosity Meas. ~ 10^{-3}

Diagnostic Tools: Parity-Violating Single Longitudinal Spin Asymmetries



$\mu = 0.00066$
$\sigma = 0.0156$
$\chi^2/\mathrm{dof} = 1.12$



$\mu = 0.0215$
$\sigma = 0.0163$
$\chi^2/\mathrm{dof} = 1.06$

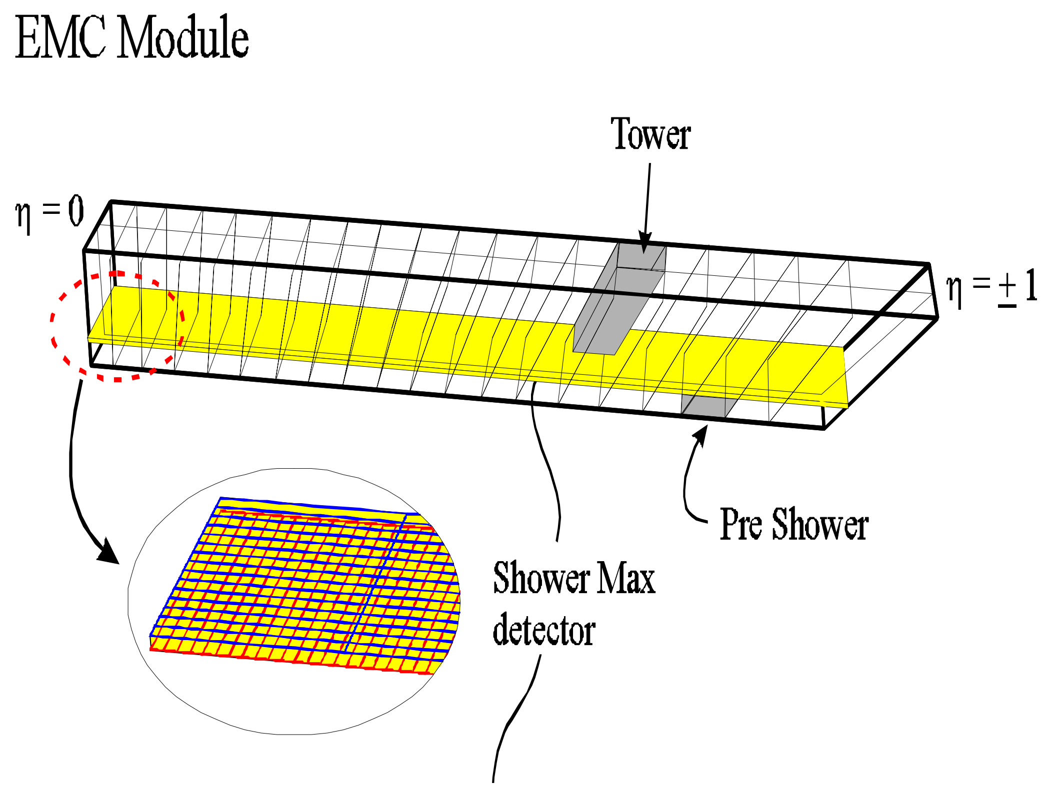
Run Number

Parity-violating single longitudinal spin asymmetries consistent with 0.

Status

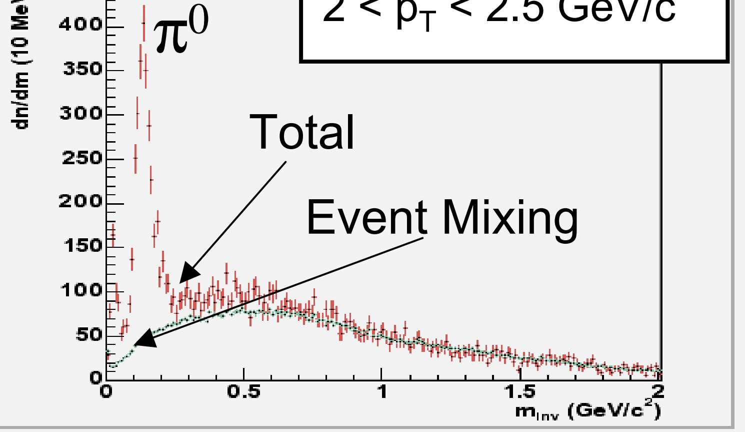
Barrel EMC

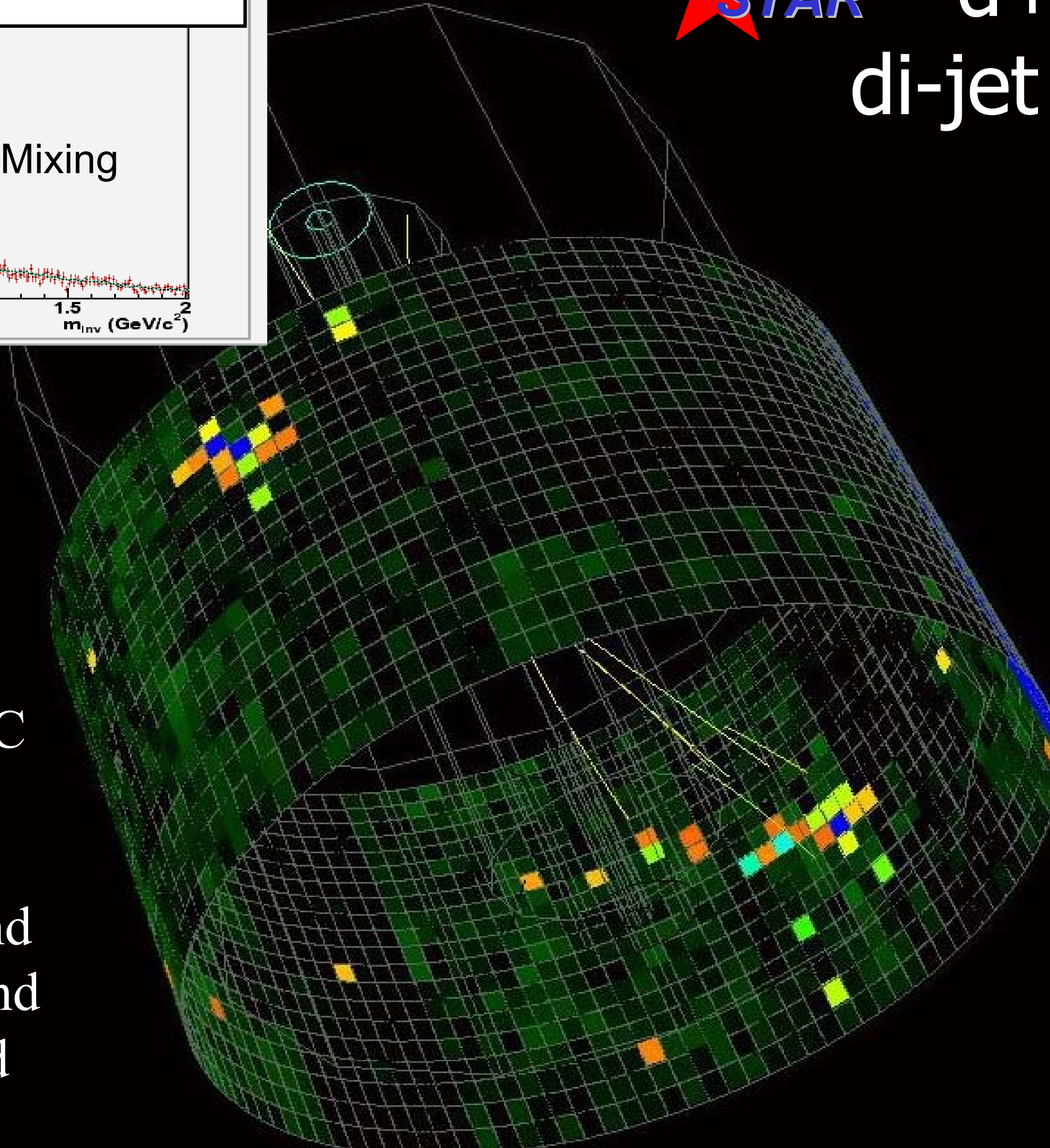
- Sampling Pb-Scintillator
- $-1.0 < \eta < 1.0$
- Full azimuthal coverage
- 120 modules
  - $(\Delta\eta, \Delta\varphi)_{module} \sim (1.0, 0.1)$
  - 40 towers/module
  - Depth = 21 X_0
  - $(\Delta\eta, \Delta\varphi)_{tower} \sim (0.05, 0.05)$
  - $dE/E \sim 16\%/\sqrt{E}$
- Shower Max Detector (SMD)
  - Positioned at ~ 5 X_0
  - High spatial resolution
  - $(\Delta\eta, \Delta\varphi) \sim (0.007, 0.007)$



- 60 modules (half barrel) used for data taking in runs 3,4.
- 112/120 modules installed by 10/04.
- complete barrel EMC ready for data taking by 10/05.

STAR d+Au di-jet event



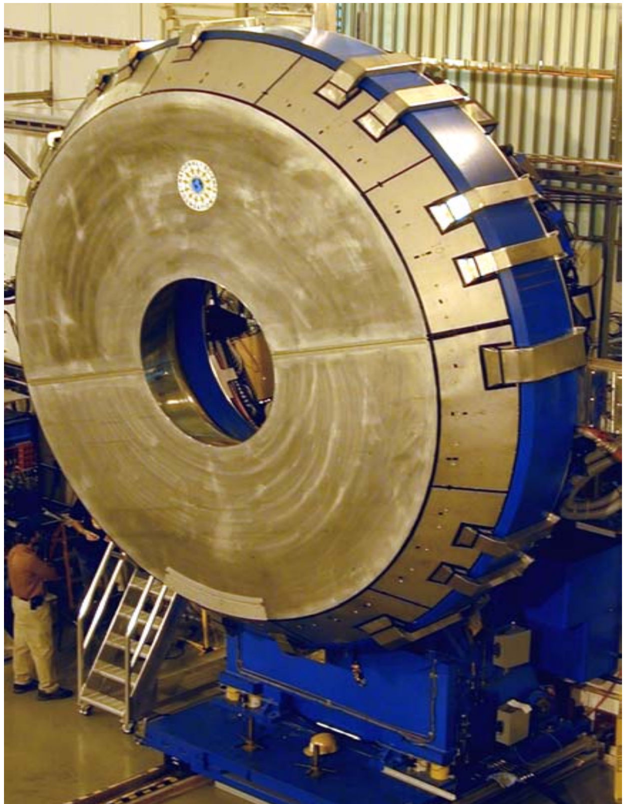


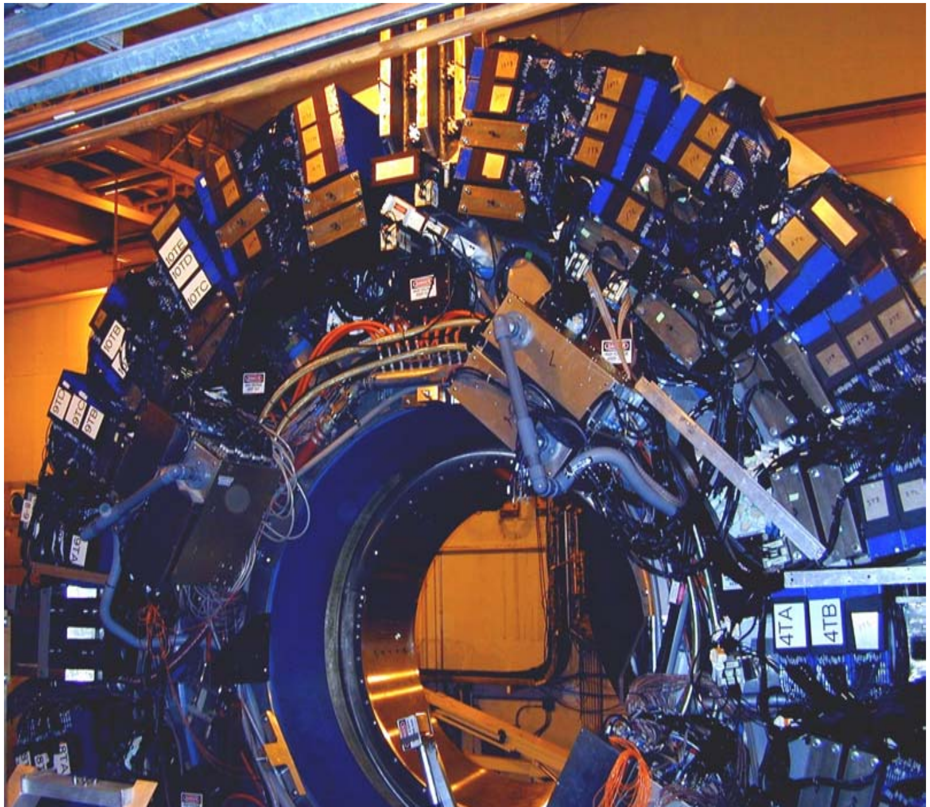
Full barrel EMC critical for jet, electron (from heavy flavor and W,Z bosons) and γ triggering and reconstruction.

EEMC Installation

Installed for 2004 run:

- ***All active elements: 720 towers, ~7000 SMD strips, 1440 preshower tiles, 720 postshower tiles, ~30000 optical readout fibers***
- ***Full tower readout and STAR L0 trigger inputs***
- ***MAPMT readout for 1/3 of the SMD + preshower + postshower channels***
- ***Extensive laser and LED diagnostic systems; full HV control system***

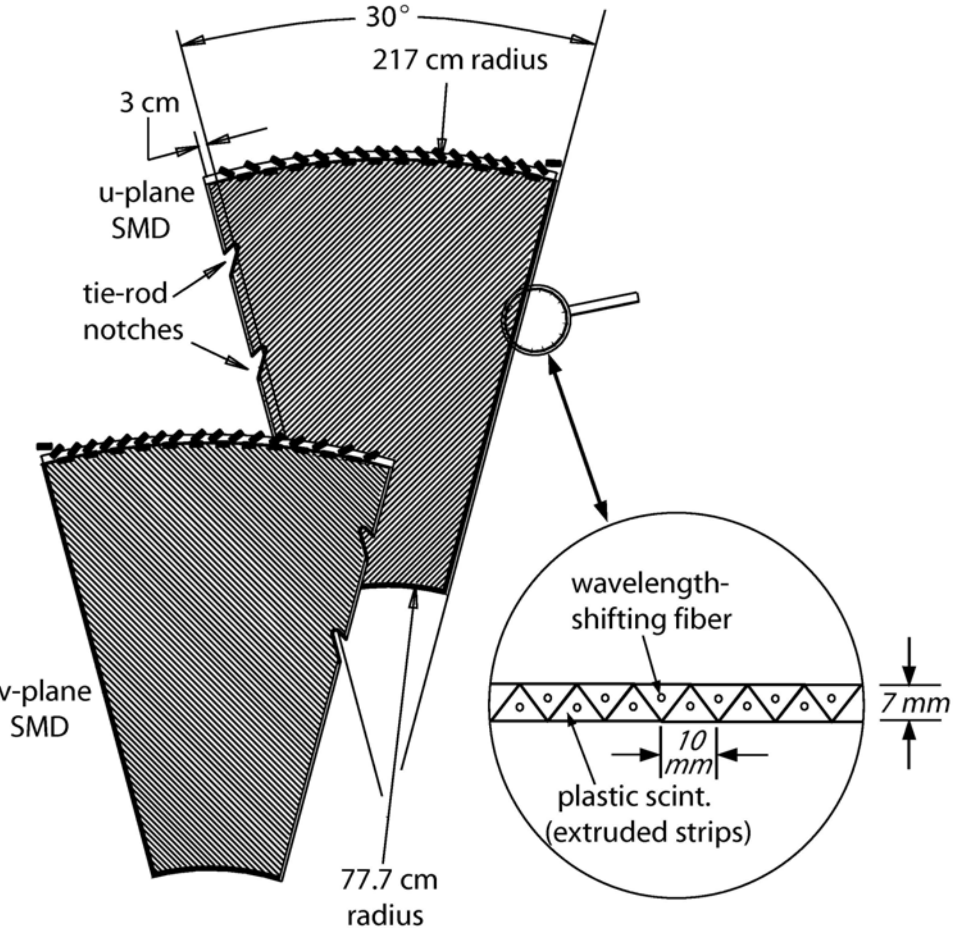


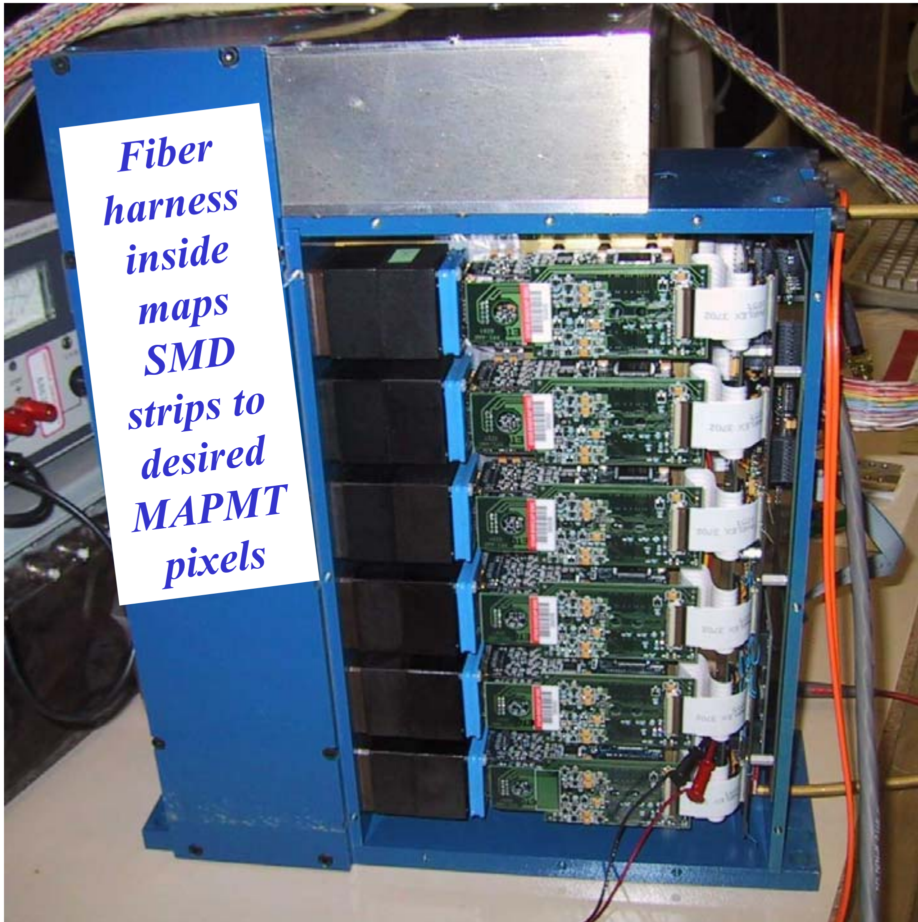


EEMC Incorporates Innovative Shower-Maximum Detector

- Modular, but gapless, design utilizes fast plastic scintillating strips of triangular cross section to measure transverse shower profiles.
- Critical for γ/π^0 and electron/hadron discrim.

- Signals from each of ~7000 strips integrated and 12-bit digitized every Xing in novel, compact, fast electronics.
- Same multi-anode PMT-based FEE used for pre/post-shower readout (~2K channels) funded through MIT and STAR.



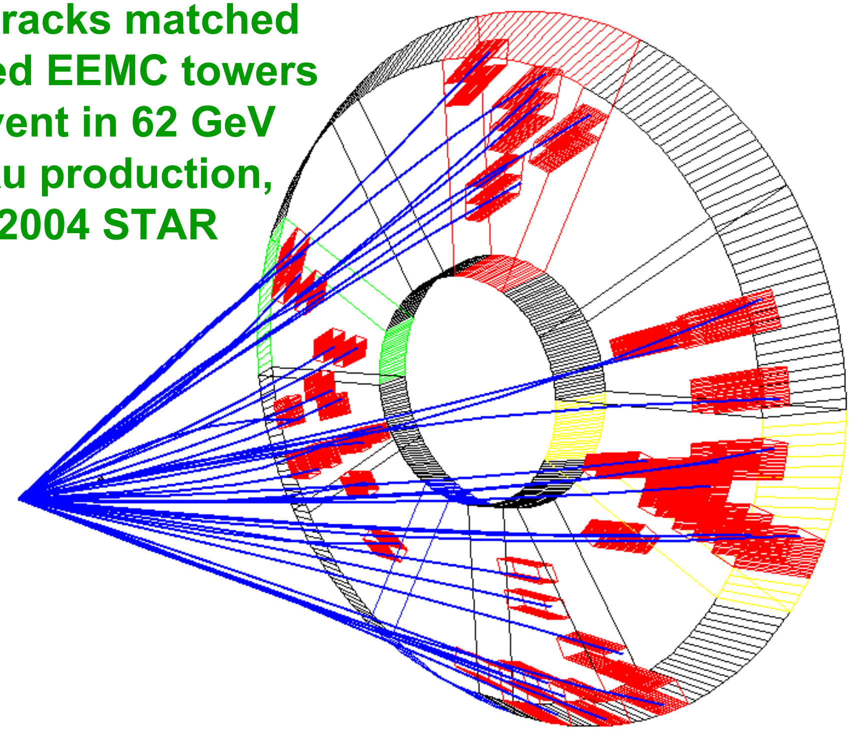


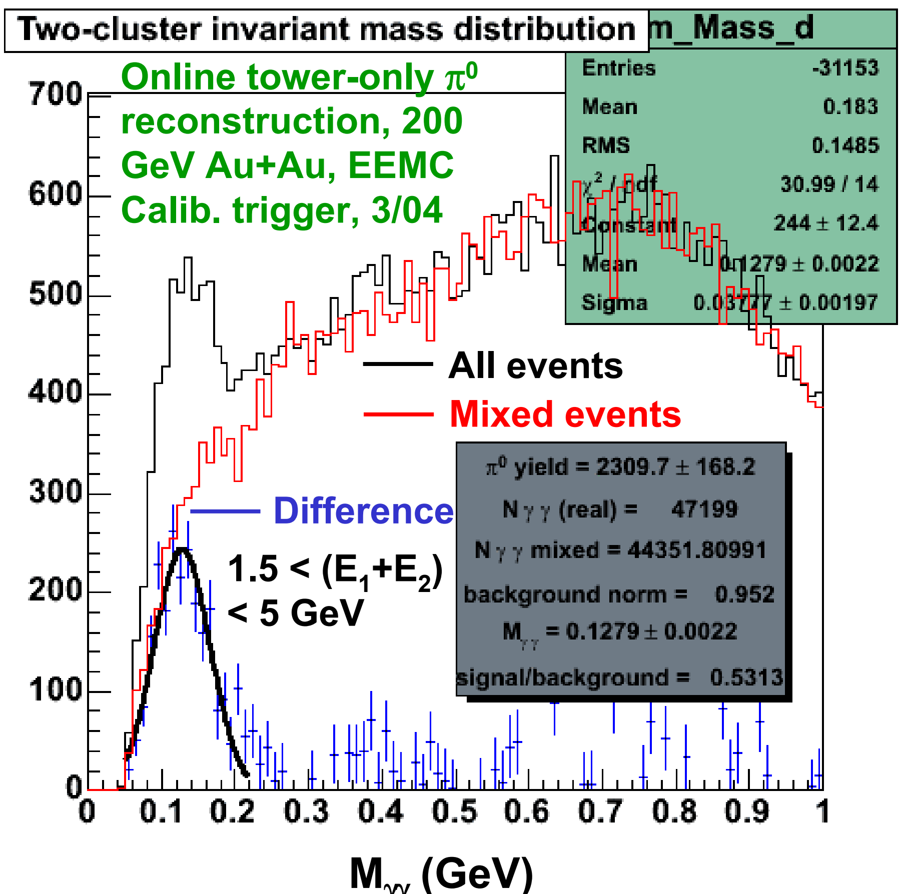
Progress Toward EEMC-Based Physics Analysis

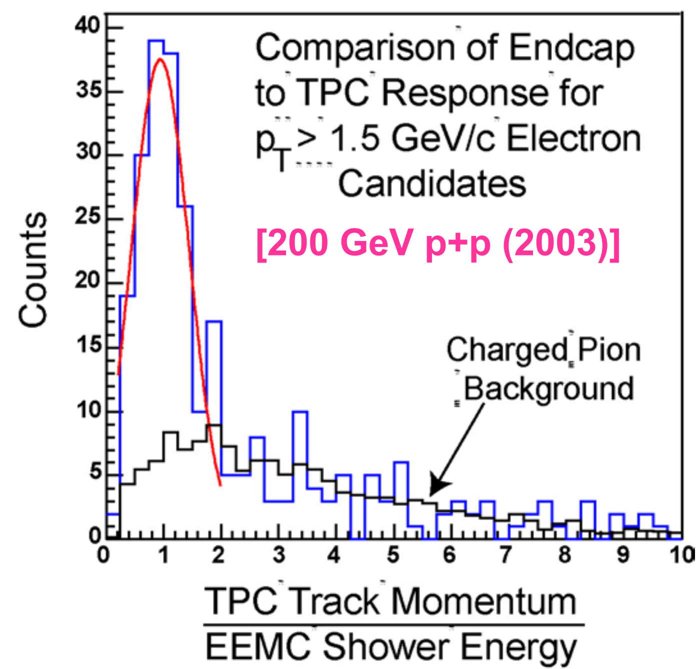
➢ ***EEMC alone permits MIP and π^0 reconstruction (below) for gain calibration and physics***

➢ ***TPC tracking to EEMC permits electron ID and enhances MIP ID***

TPC tracks matched to fired EEMC towers for event in 62 GeV Au+Au production, from 2004 STAR data.

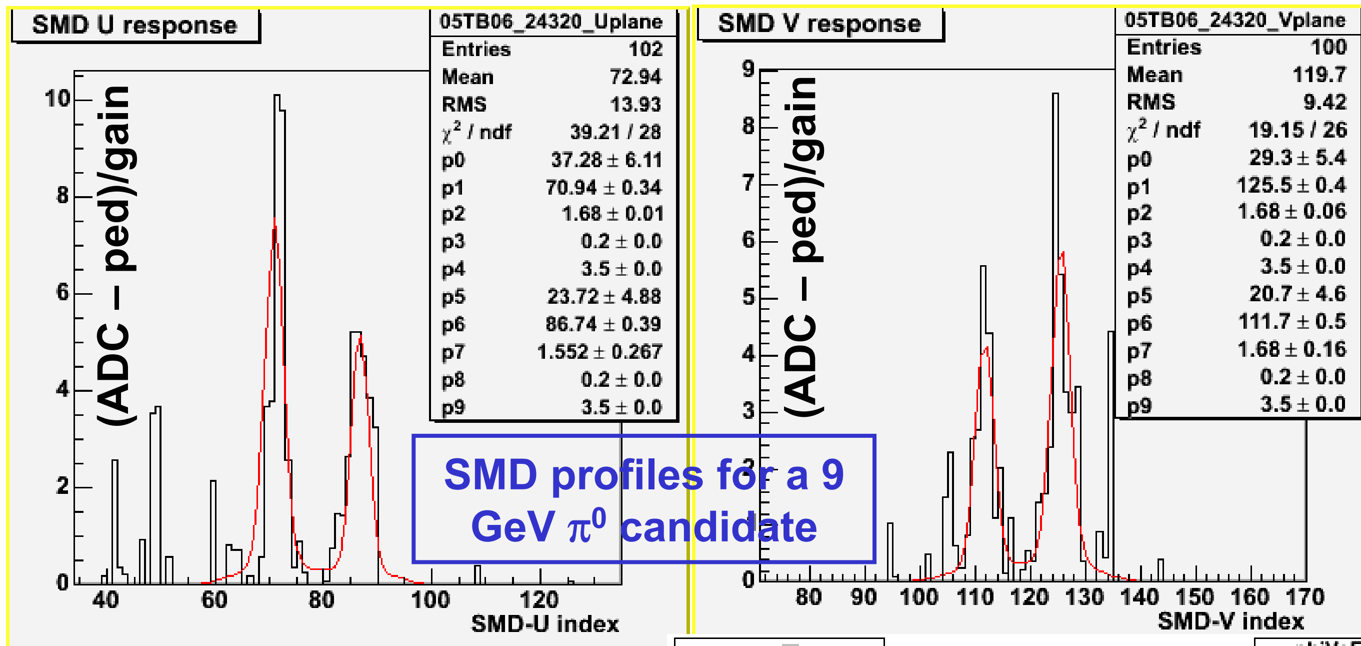




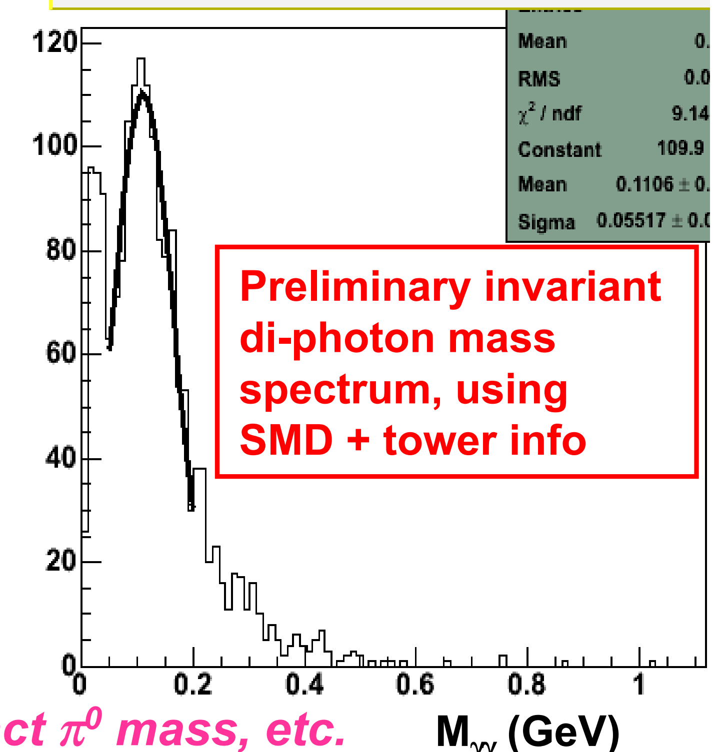


SMD-aided π^0 Reconstruction Progress

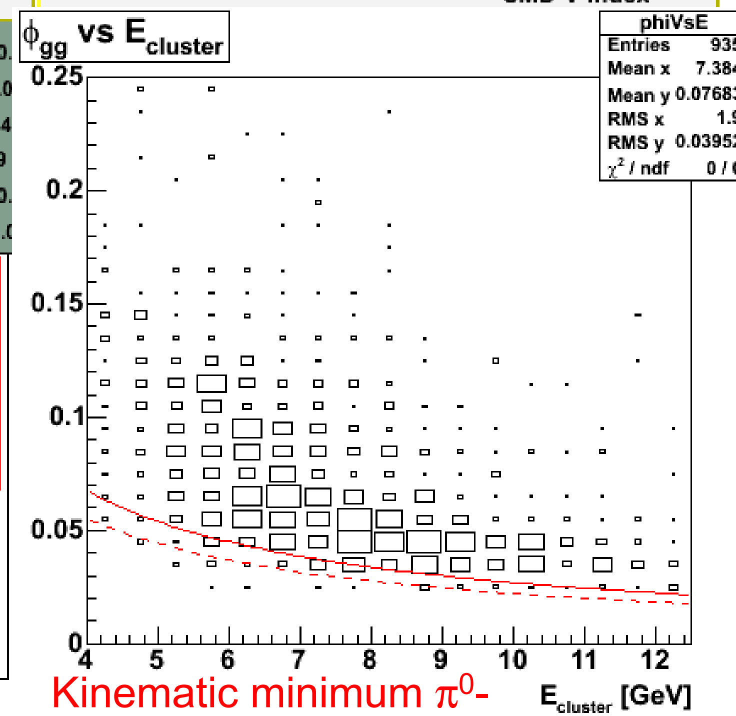
- *Focus for now on isolated tower clusters > 4 GeV in 200 GeV p+p run 4 data*
- *Look for events with 2 clear SMD peaks in at least one plane, within leading tower acceptance*
- *Fit 'calibrated' 2-gaussian peaks to SMD profiles, to extract opening angle and energy sharing*
- *Combine tower + SMD info to extract π^0 mass, etc.*



SMD profiles for a 9 GeV π^0 candidate



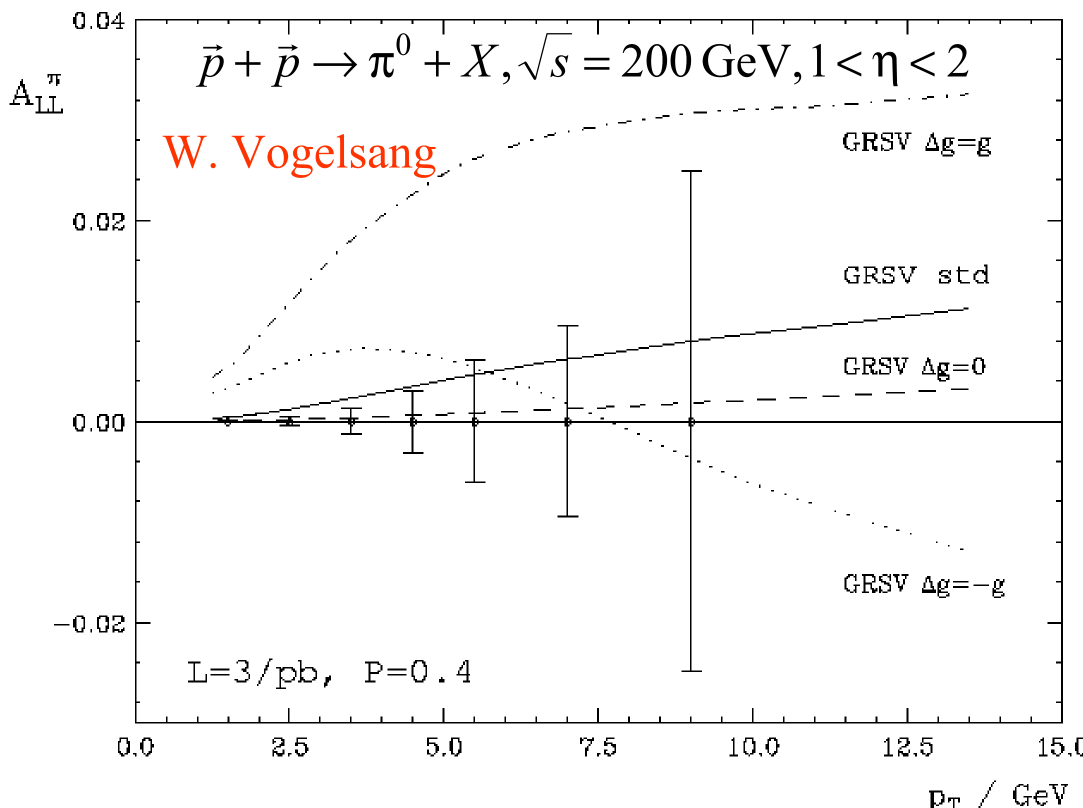
Preliminary invariant di-photon mass spectrum, using SMD + tower info



Kinematic minimum π^0-decay opening angle

EEMC will be fully ready for physics production in 2005!

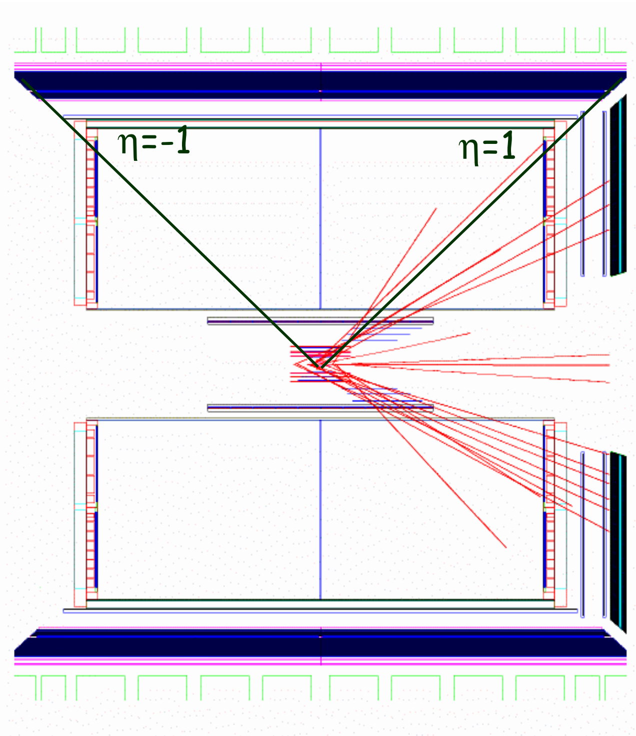
- All EEMC towers + trigger and 1/3rd of SMD and pre/post-shower systems participated fully in 2004 run and worked well.
- Installation during present shutdown focusing on remaining 32 MAPMT boxes to complete SMD/pre/post readout (all component deliveries on schedule).
- Considerable analysis work for calibrations of all subsystems is ongoing and looks very encouraging.
- EEMC-based physics analyses of 2004 STAR data will focus on:
  - π^0-gated di-hadron correlations in 62 and 200 GeV Au+Au (quenching of q vs. g jets)
  - $A_{LL}(\pi^0)$ in 200 GeV p+p (sensitivity to ΔG in proton)
  - Evaluation of efficiency & bias for different jet triggers, + extended coverage for A_{LL}(jets) in 200 GeV p+p
  - Search for high-p_T direct photon yield in p+p and Au+Au



Integrated tracking approach - STAR tracking upgrade

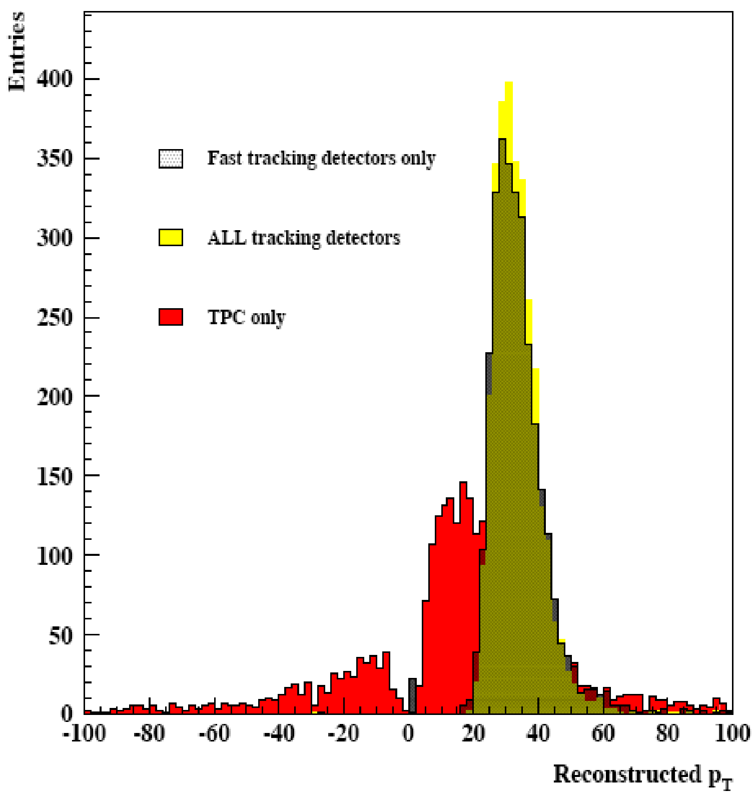
- Simulated forward p_T resolution ($1 < \eta < 2$)

  - Forward p_T reconstruction: π^-
    - True p_T = 30 GeV
    - Range in η: $1 < \eta < 2$



  - Simulated fast tracking configuration:
    - Inner (fast) configuration: 3 silicon layers
    - Outer (fast) configuration: 2 triple GEM layers

  - Reconstructed p_T for various detector configurations:



Integrated tracking approach of pixel upgrade and inner silicon upgrade in combination with forward GEM tracker mandatory!

Overview and timeline - STAR tracking upgrade

- Integrated Tracking upgrade
  - The study of heavy flavors and W production will require an upgrade of the STAR inner/forward tracking system
    - Integrated tracking design of a new inner and forward STAR tracking system is mandatory
    - Staging of tracking upgrade in accordance with readiness of detector technology and beam development
  - STAR tracking upgrade program actively pursued by several STAR institutions
  - STAR tracking upgrade working group (Convenor: Ernst Sichtermann (LBL) and Bernd Surrow (MIT))
    - W physics case (Flavor structure of quark helicities)
    - Heavy flavor spin case under investigation (Strong dependence of partonic asymmetry on heavy quark mass- study of heavy flavor tagged jets): STAR Heavy flavor program driven by STAR's relativistic heavy-ion program
    - Simulation work and integrated design of detector layout based on pixel, silicon and triple-GEM technology (R&D work has been started) has been started
  - Possible scenario:
    - Stage 1: Installation of pixel detector together with a minimal new barrel tracking detector based on silicon technology ($-1 < \eta < 1$) (Heavy Flavor Physics)
      - Goal: Proposal by summer 2005
      - Installation of new inner tracking system in time for next long Au-Au run
    - Stage 2: Upgrade of the forward (inner silicon and outer GEM) tracking system ($1 < \eta < 2$) (W physics)
      - Goal: Proposal by summer 2006
      - Installation of forward system in time for 500GeV production run
  - Dedicated time for machine development with polarized protons to achieve high luminosity and high polarization is vital for the success of this novel program!

Documented in STAR decadal plan and AGS/RHIC PAC

GEM development - STAR tracking upgrade

Triple-GEM tracking detector development

- Design of at least three triple-GEM chambers to be installed and tested at STAR under beam conditions:
  - Industrial production of GEM foils: Tech Etch Inc., Plymouth, MA
  - Develop and manufacture GEM foils for applications in triple-GEM detectors and other applications such as GEM TPC readout schemes (First gain tests are encouraging!)
  - Manufacture of 1D/2D-readout structures
  - Design of a flexible GEM chamber to install and replace GEM foils
  - Design of a chip readout system based on APV25-S1 (Used for CMS silicon tracker and COMPASS triple-GEMs)

RHIC R&D team:

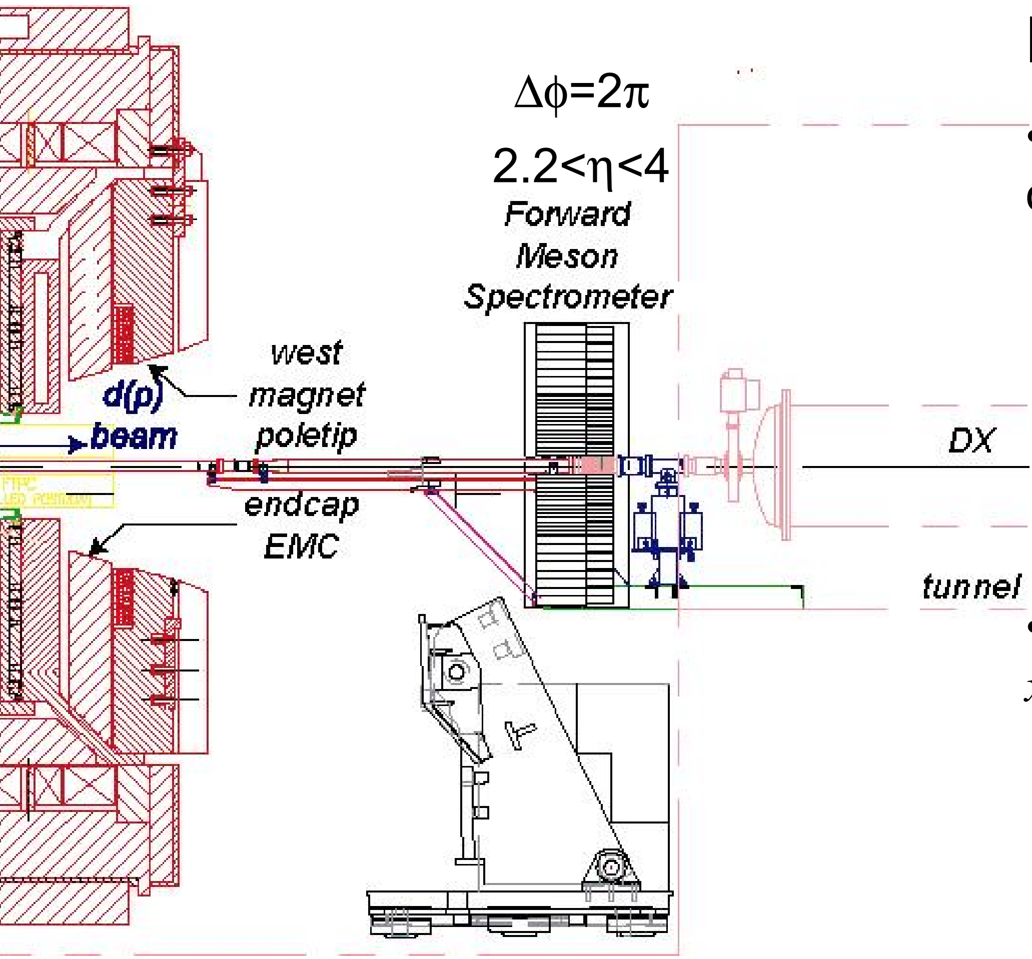
- Collaboration between STAR/PHENIX: ANL, BNL, MIT, Yale
- Tech Etch Inc. agreed to formulate a SBIR proposal by January 2005 in collaboration with ANL, BNL, MIT and Yale

R&D and construction laboratory:

- In order to realize the design and construction of a GEM-type tracking detector for the RHIC collider experiments, a clean-room to handle, inspect and test GEM-foils besides the actual detector assembly is urgently needed
  - Strong interest by several MIT faculty and staff members to establish such a test and construction laboratory at MIT-LNS and MIT-Bates using two existing clean room setups used for the BLAST drift chamber construction
  - Profit from clean room experience at MIT Microsystems Technology Laboratory (Several clean room accessories are available for free from the MIT Microsystems Technology Laboratory based on industry donations)
- Other potential location: Yale

Forward Meson Spectrometer

Conceptual Design



Physics Motivation:

- probing gluon saturation in p(d)+A collisions via…
  - large rapidity particle production ($\pi^0,\eta,\omega,\eta',\gamma,K^0,D^0$) detected through all γ decays.
  - di-jets with large rapidity interval (Mueller-Navelet jets)
- disentangling dynamical origins of large x_F analyzing power in $p_\uparrow$+p collisions.

Issues

• Adequate time to operate RHIC with polarized protons to attain polarization and luminosity goals required for STAR spin program.

• Increase robustness of barrel EMC readout electronics

⇒ eliminate front-end electronics power supply problems and reduce data corruption

• Complete development of analysis tools for jet, photon and electron finders.

• Complete forward tracker upgrade to allow charge-sign discrimination for *W* physics program.

Backup Slides

Scenarios for Evolution of STAR Spin Program

<table>
<tr><th>Fiscal Year</th><th colspan="2">27 weeks/year BUP (submitted 8/03)</th><th colspan="2">“Optimized Constant Effort” Scenario</th><th colspan="2">32 weeks each year run scenario</th></tr>
<tr><td rowspan="2">2004</td><td rowspan="2">5+14 Au+ Au 200</td><td rowspan="2">5+0 pp 200</td><td rowspan="2">5+14 Au+ Au 200</td><td rowspan="2">5+0 pp 200</td><td rowspan="2">5+14 Au+ Au 200</td><td rowspan="2">5+0 pp 200</td></tr>
<tr></tr>
<tr><td rowspan="2">2005</td><td rowspan="2">5+9 Au+ Au Escan</td><td rowspan="2">5+5 pp 200</td><td></td><td></td><td rowspan="2">6+8 Au+ Au Escan</td><td rowspan="2">5+10 pp 200</td></tr>
<tr><td rowspan="2">6+11 Au+ Au Escan</td><td rowspan="2">5+12 pp 200</td></tr>
<tr><td rowspan="2">2006</td><td rowspan="2">5+9 d+Au 200</td><td rowspan="2">5+5 pp 200</td><td rowspan="2">5+8 d+Au 200</td><td rowspan="2">5+11 pp 200</td></tr>
<tr><td rowspan="2">5+9 d+Au 200</td><td rowspan="2">5+13 pp 200</td></tr>
<tr><td rowspan="2">2007</td><td rowspan="2">5+5 Au+ Au 200</td><td rowspan="2">5+9 pp 200</td><td rowspan="2">5+10 Au+ Au 200</td><td rowspan="2">5+9 Cu+ Cu 200</td></tr>
<tr><td rowspan="2">5+15 Au+ Au 200</td><td rowspan="2">5+8 Cu+ Cu 200</td></tr>
<tr><td rowspan="2">2008</td><td rowspan="2">5+10 Au+ Au 200</td><td rowspan="2">5+5 pp 500</td><td rowspan="2">5+10 Au+ Au 200</td><td rowspan="2">5+9 pp 200</td></tr>
<tr><td></td><td></td></tr>
<tr><td>$\int L_{max}$ dt pp 200</td><td colspan="2">76 pb^{-1}</td><td colspan="2">88 pb^{-1}</td><td colspan="2">156 pb^{-1}</td></tr>
<tr><td>$\int L_{max}$ dt post-TOF Au+Au</td><td colspan="2">1.4 nb^{-1}</td><td colspan="2">1.6 nb^{-1}</td><td colspan="2">2.1 nb^{-1}</td></tr>
<tr><td>What’s missing?</td><td colspan="2">Any Cu+Cu 200; 2nd+3rd long pp</td><td colspan="2">3rd long pp; 2 pp devel. chances</td><td colspan="2">1 pp devel. chance</td></tr>
</table>

Twenty-Year Planning Study for RHIC at BNL, BNL-71881-2003